Hetherington, H.C.
An investigation of the rae beta-particle spectrum in the energy range 0-65 kev.

THE UNIVERSITY OF ALBERTA

"AN INVESTIGATION OF THE RaE BETA-PARTICLE SPECTRUM IN THE ENERGY RANGE 0-85 KEV."

A DISSERTATION

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

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BY

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The undersigned hereby certify that they have read and recommend to the School of Graduate Studies for acceptance, a thesis entitled, "An investigation of the RaE beta-particle spectrum in the energy range 0-65 Kev.", submitted by Hilliard Cameron Hetherington B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

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Date. May 5, 1950

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Introduction

A large number of investigators have made measurements on the beta-ray spectrum of RaE. The majority of these investigations were carried out to ascertain the end-point energy and the most probable energy of the spectrum.

Investigation of the low energy end (0-60 Kev.) of the spectrum was not attempted until 1924 when H.O.W. Richardson (1) made measurements of the range of the low energy rays using a Wilson Cloud Chamber, and converted these ranges to energies. He used a RaE source deposited on gold and silver leaves. The source was centrally placed in the chamber and stereoscopic photographs were taken of the tracks, using a double camera arrangement.

His results showed a surprisingly large number of low energy tracks, which exhibited a broad maximum between 15-30 Kev. and a higher one at approximately 55 Kev.(Plate 1). The maximum at approximately 55 Kev. was higher than that between 200-400 Kev. predicted by the existing

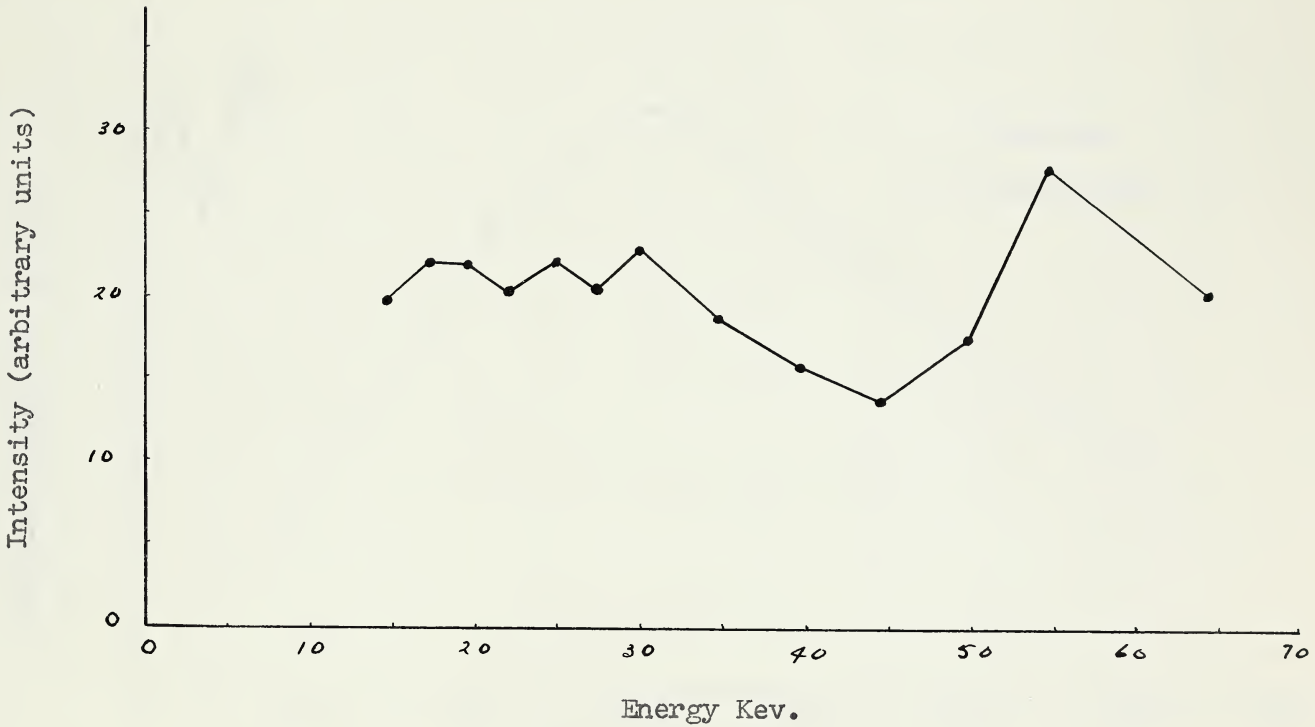


Plate 1 RaE low energy spectrum (H.O.W. Richardson)

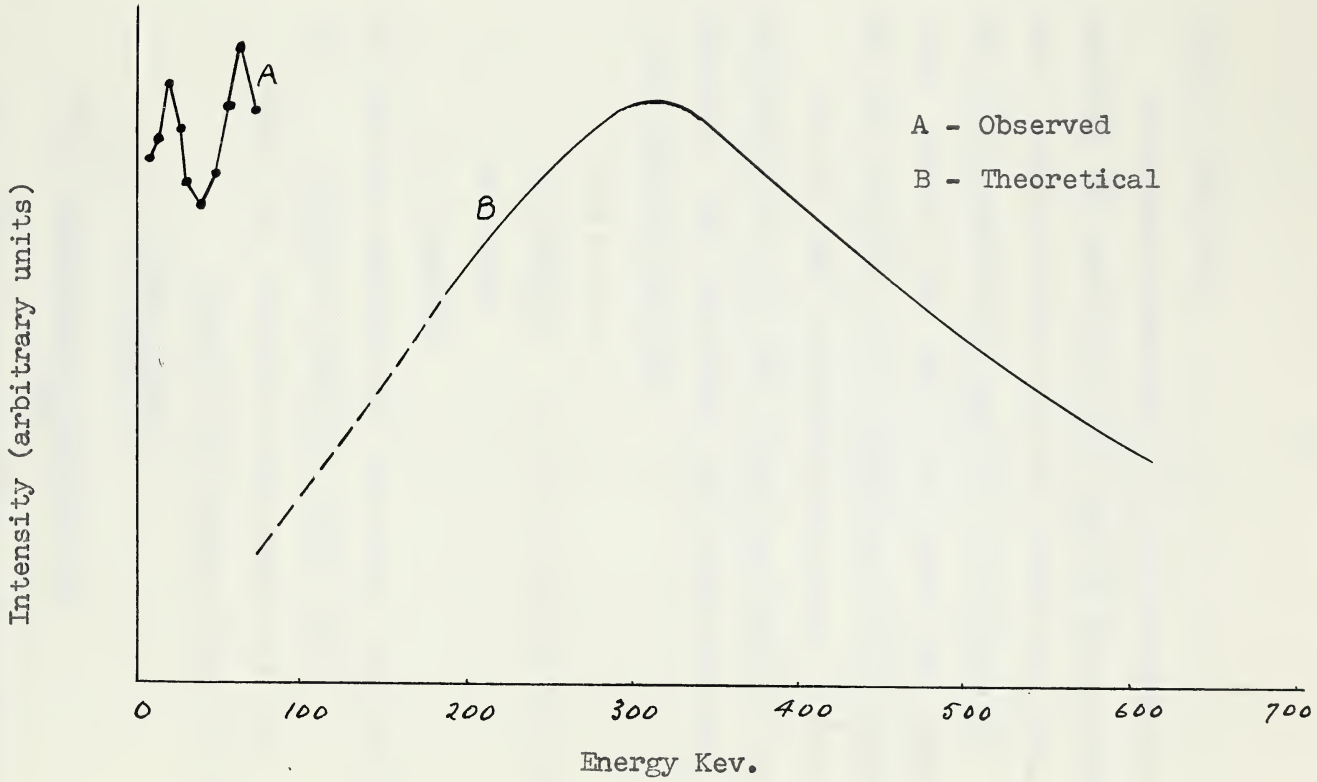


Plate 2. Comparison of observed with theoretical distribution (1)

theory. (Plate 2).

Richardson discarded the apparent excess of particles in the region less than 15 Kev. as being due to back scattering from the source support. This left unexplained however, the surprising number above 15 Kev. and up to the 60 Kev. peak, and this behavior is in disagreement with theory.

In 1934 Fermi published his theory of beta-disintegration (3). This theory was based on the assumption that beta-decay took place according to the nuclear reaction.

$$n \longrightarrow p + e + \eta$$

n- neutron e- electron (Beta-particle)

p- proton

η - neutrino

The resulting equation for the energy spectrum is

(A) $$N(E)dE = E\left(E^2-1\right)^{1/2}(E_o - E)^2 dE \quad (4)$$

where N(E)= number of beta particles whose energy lies between E and (E+dE)

$$E = \frac{\text{Total energy}}{m_o c^2}$$

$$\left(E^2-1\right)^{1/2} = \frac{\text{momentum of electron (P)}}{m_o c}$$

$$E_o = \frac{\text{Total energy available in a disintegration}}{m_o c^2}$$

In 1936 Kurie, Richardson and Paxton (5) rearranged the equation so that it could be readily subjected to test by the observed data. They plotted

$$F(E) = \left(\frac{N(E)}{E(E^2-1)^{1/2}} \right)^{1/2}$$

against the energy E.

By equation (A)

$$F(E) = E_o - E$$

Hence the plot should give a straight line, cutting the E-axis at E_o which gives the end-point energy.

The experimental data did not support the Fermi theory at this time.(Plate 4). The thick target curve is typical of the experimental evidence which lead Konopinski and Uhlenbeck to introduce their alternative theory (6). By a modification to the Fermi theory they obtained the result that

$$(B) \qquad N(E)dE \simeq E(E^2 - 1)^{1/2}(E_o - E)^4 dE$$

For a Kurie plot

$$F(E) = \left(\frac{N(E)}{E(E^2-1)^{1/2}} \right)^{1/4}$$ is plotted against E.

This new formula (B) moved the maximum of the

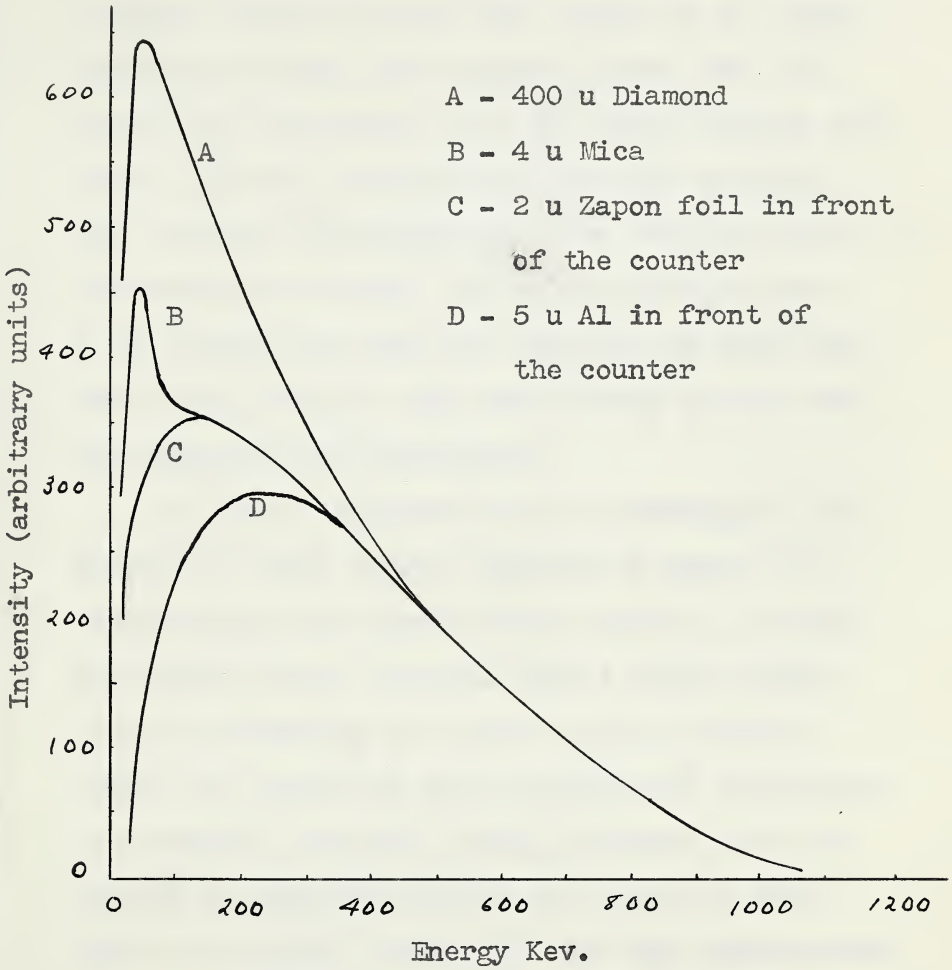


Plate 3. RaE energy distribution showing the effects of back-scattering from heavy source supports (8).

spectrum to lower electron energies. Much of the experimental data on thick targets now gave straight lines but very high values of E_o. Later experiments using thin targets showed that the Kurie plots according to K. U. Theory dropped off, (Plate 5) which demonstrated that the straight line portion was accidental. Also from the mass differences of nuclei the values of E_o by the K. U. theory were much too high in all cases but ~~that~~ those given by the Fermi theory agreed with the measured mass difference.

In 1939 A. Flammersted (8) investigated the effects of heavy source supports by means of a spectrograph and Geiger Muller counter. He found that heavy source supports gave a large amount of back-scattering and hence a false maximum (Plate 3). Using the most satisfactory conditions he obtained a complete energy spectrum which he plotted by the Kurie method for both the Fermi and K. U. theory. (Plate 6). The high extrapolated end point energy and dropping off given by the K. U. theory is evident, as is also the

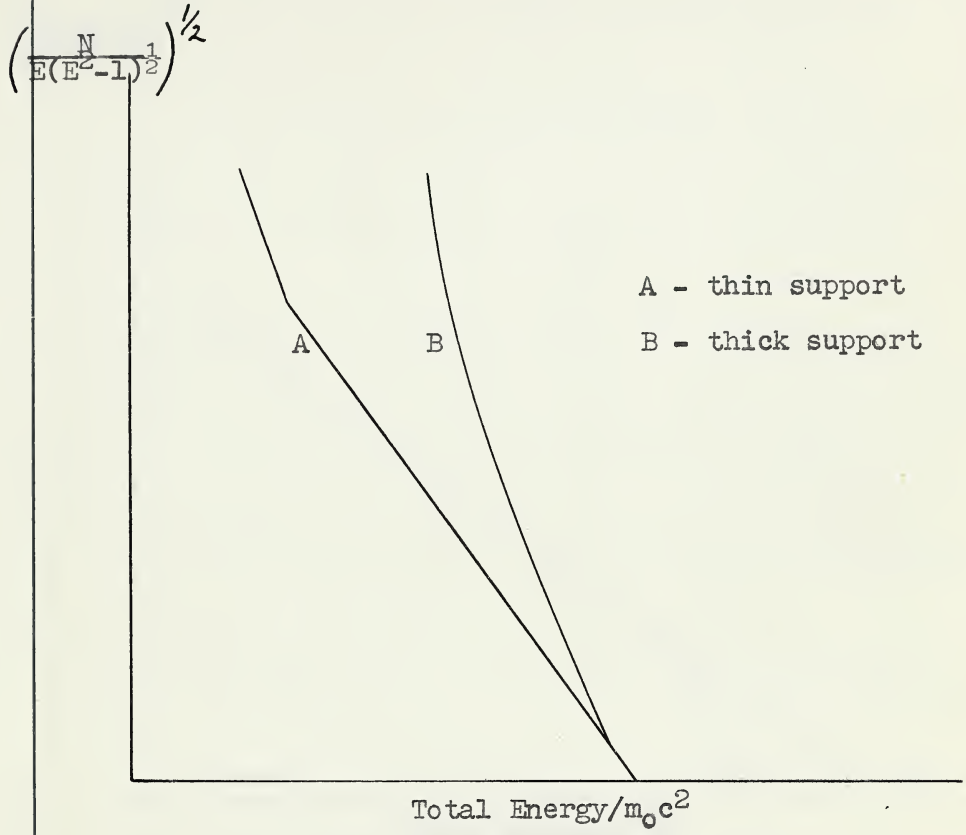


Plate 4 Kurie plot of Fermi theory showing the effect of source supports.

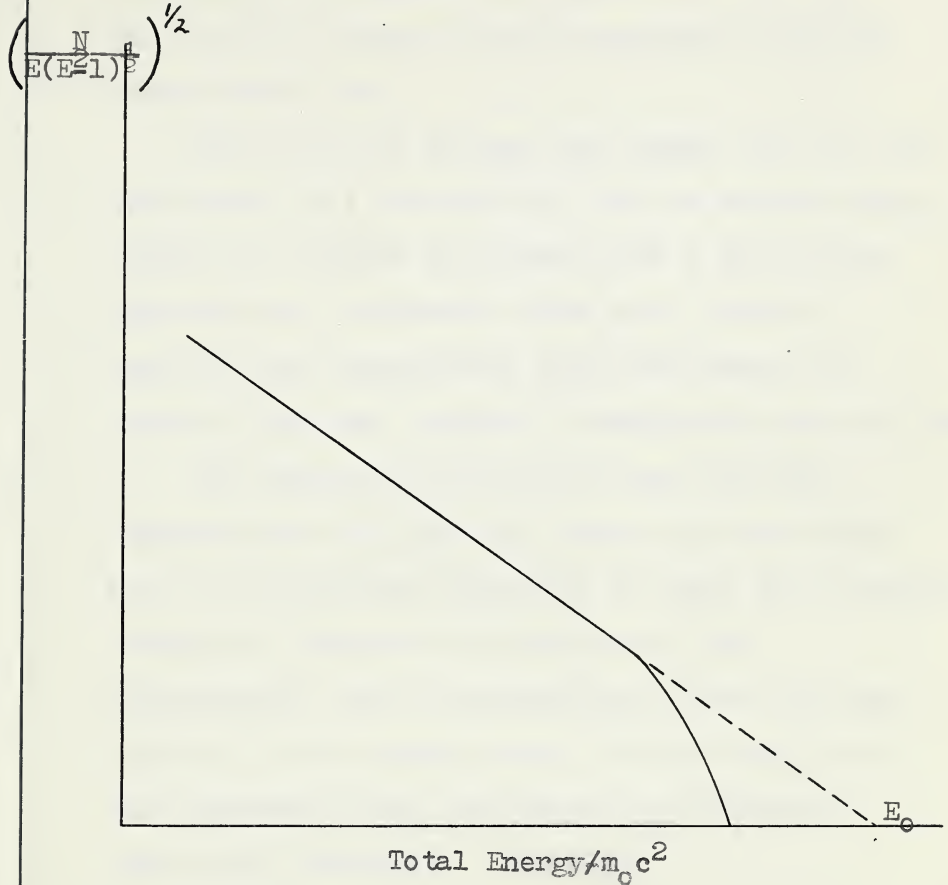


Plate 5 Typical Kurie plot of K.U. theory. Note dropping off of the curve and high extrapolated value of E_o

disagreement of the Fermi theory with the middle energies. He concluded that neither the Fermi nor the K. U. theory agreed completely with the experimental data.

More recently Waltner and Rogers (9) and (10) and Madsen (11) investigated the low energy range (Plate 7). Waltner and Rogers used a RaE source deposited on a collodion film 0.2 u thick in some of their experiments and a RaE vapour in others. They also obtained a maximum at about 30 Kev.

The results of (1),(11),(9) and (10) all disagree with the existing theory of beta-decay and it is therefore important to study this problem further to determine the status of this disagreement. This investigation, which has been confined to the energy range 0 to 65 Kev. in the RaE spectrum is for the purpose of obtaining additional evidence.

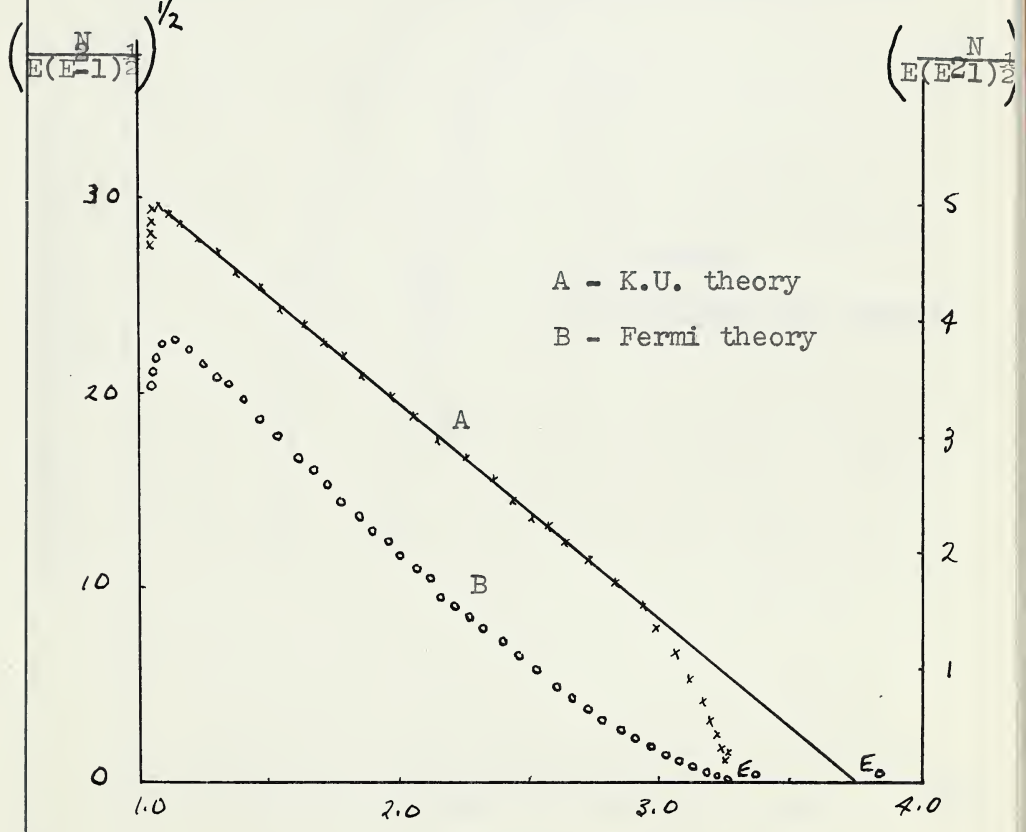


Plate 6 Kurie plots of the RaE spectrum

(Flammersted)

Note dropping off of K.U. theory and high extrapolated value of E_o

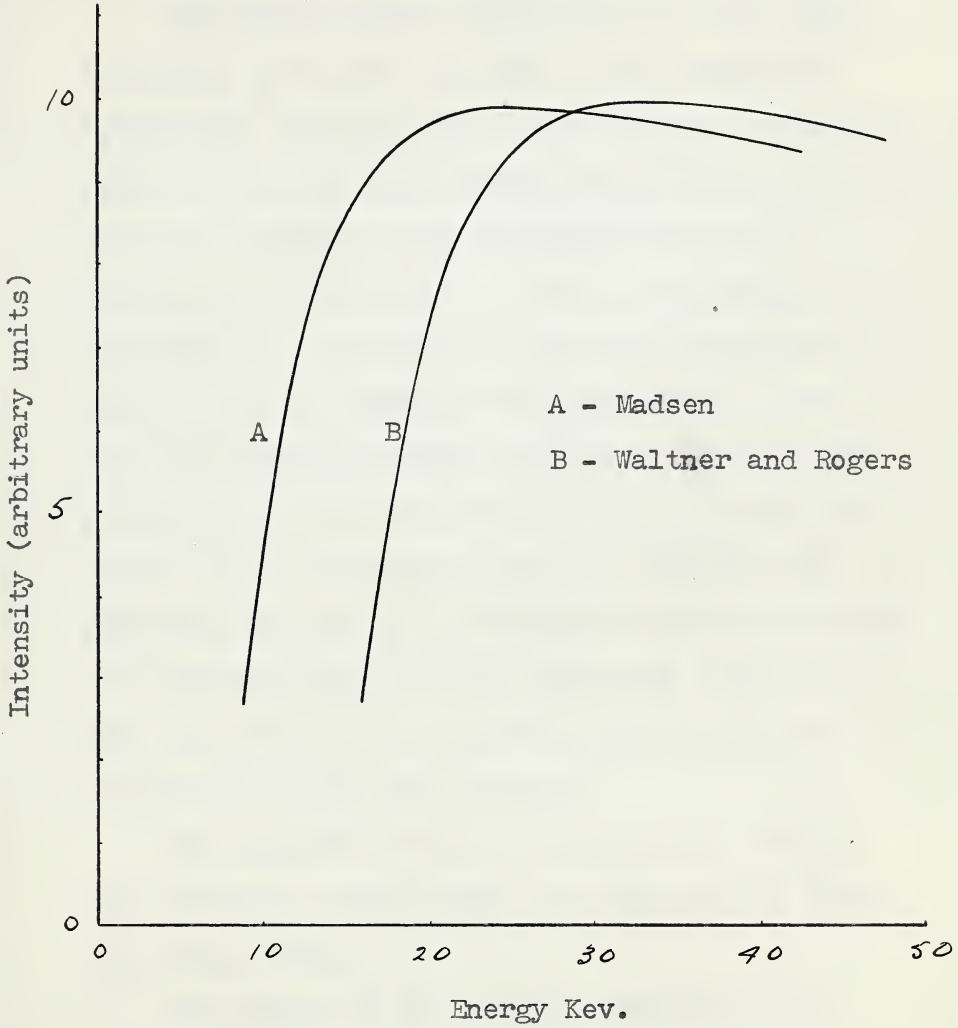


Plate 7 - RaE low energy spectrum

Apparatus

1. Cloud Chamber Proper

The Cloud Chamber (Plate 16) is of the type developed by Gilbert and Dee in the Cavendish Laboratory. It was built in the National Research Council shops at Chalk River. It is of the pressure actuated diaphragm type in which the working chamber is sealed off by a rubber diaphragm. # Expansion is obtained by a pressure differential between the two sides of the diaphragm. In our case the working chamber is kept at atmospheric pressure and the lower side of the diaphragm may either be at atmospheric pressure (compressed position) or open to an evacuated chamber by means of a sylphon bellows valve (expanded Position). The valve (Plate 17) is actuated by a solenoid controlled by the main circuit.

The expansion ratio is adjusted by raising and lowering a plate under the diaphragm by means of a large screw.

The bottom of the chamber consists of a perforated brass plate, over which is a layer of

1/32" Natural Rubber sheet obtained from the Ontario Rubber Co.

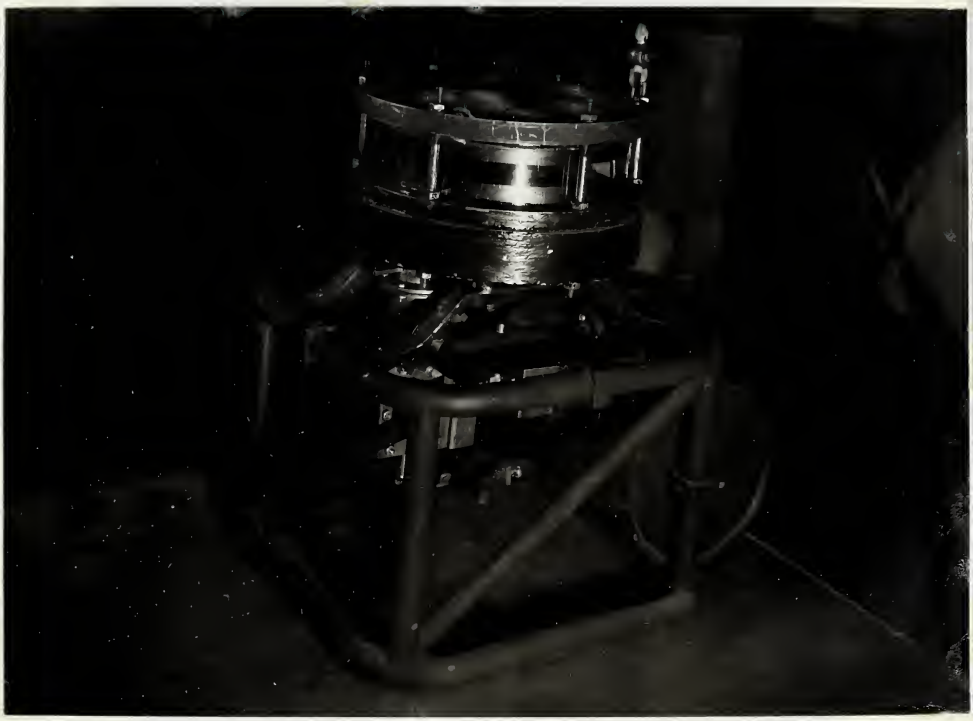


Plate 16

Cloud chamber proper

Plate 16a

Cloud chamber completely assembled

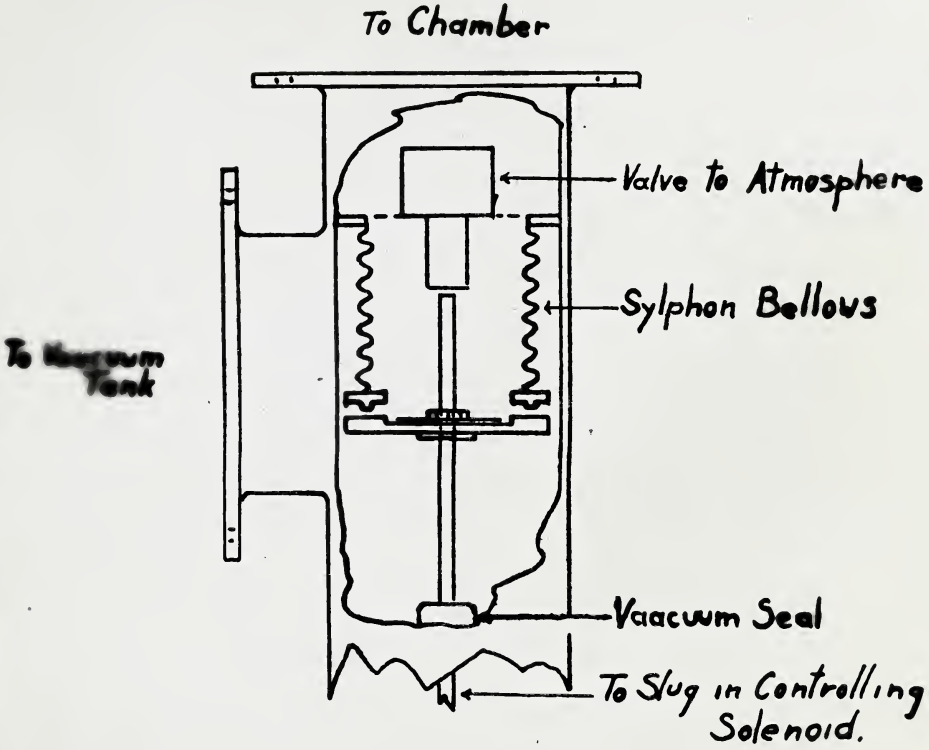


Plate 17

Sylphon Bellows Mechanism.

black velveteen, stretched taut on a circular hoop of brass. The velveteen eliminates stray light from the chamber floor and permits a non-turbulent flow of air to take place during an expansion.

The walls of the chamber are made of lucite 1/4" thick and 2" high. The only disadvantage of walls of this type seems to be that they are slightly soluble in certain organic solvents. For this reason acetone is not used in the chamber. An aquadag ring one inch high is painted around the bottom of the lucite wall to prevent the beam reflecting off the bottom of the chamber into the camera.

The top of the chamber is of glass, 12/32" thick, showing no flaws or imperfections. A 3/8" aquadag ring is painted around the inner surface. When the chamber is in operation a 400 volt clearing field is applied between this ring and the floor of the chamber. The high voltage is connected to the ring by means of two aquadag strips which are painted to the edge of the glass top at

diametrically opposite points. Connection is made to two tinfoil strips which are inserted between the top and the walls at the aquadag strips. The seal between the walls and top and bottom is accomplished by means of 1/16" natural rubber gaskets.

The working mixture is introduced into the chamber by means of a pipe which is threaded into the base at one edge, and is closed at the upper end with a screw plug.

The valves, expansion regulation screw, and movable external connections are packed with a mixture of vacuum grease and cotton batting. The base of the chamber, which is made of cast aluminum, is painted with glyptal since the aluminum is slightly porous. This portion of the chamber is isolated from the working portion by the diaphragm and it was found that small leaks did not greatly interfere with the operation of the chamber as they were quite easily handled by the pumps.

Two Cenco Hyvac pumps in parallel, maintain a tank of about 1/5 cu. ft. capacity at a low

pressure. The tank is connected to the base of the chamber and is opened to the bottom of the diaphragm by the expansion valve.

A length of lead tubing wrapped around the base of the chamber is connected to a cold water line. This was done to reduce the temperature inside the chamber and to stabilize it during operation. In addition, reducing the temperature at the base below that of the walls and top plate eliminates fogging of the latter during operation.

2. Helmholtz Coils

The Helmholtz coils were built at the National Research Council shops at Chalk River. The inside diameter is 18" and the outside diameter is 20½". The coil forms are of 1/8" brass, 3-3/8" deep and 3-1/8" wide. A single layer of copper tubing is wound on the inside for cooling purposes, and 1080 turns of #11 H. F. copper wire per coil are spooled on the outside of the tubing. The resistance is 5.8 ohms per coil at 20 degrees Centigrade. Due to the inductance of the winding the time for the current to reach a steady value

is found to be about 1.8 seconds. For this reason it is advisable to have at least a 2 second delay for the coils.

The coil circuit (Fig. 1) consists of an A. C. relay which, when activated by the timing circuit, closes a heavy current D.C. relay to the coils. A condenser of 60 microfarads capacity was connected across the coils to prevent arcing at low currents. For high current work there is a Tungar Mercury Rectifier (189048) across the relay. This shorts the back emf. of the coils directly preventing arcing across the relay contacts.

The Helmholtz coil field uniformity was investigated (13) and found to be uniform within .5% over a region bounded by planes 2.5 cm. below and above the plane through the midpoint of the coils, and a cylinder of 9 cm. radius.

3. The Camera.

The camera (Plate I 8) was designed and built in the Physics Department by C. T. Kokotailo. It is fitted with a Leica Elmar f3.5

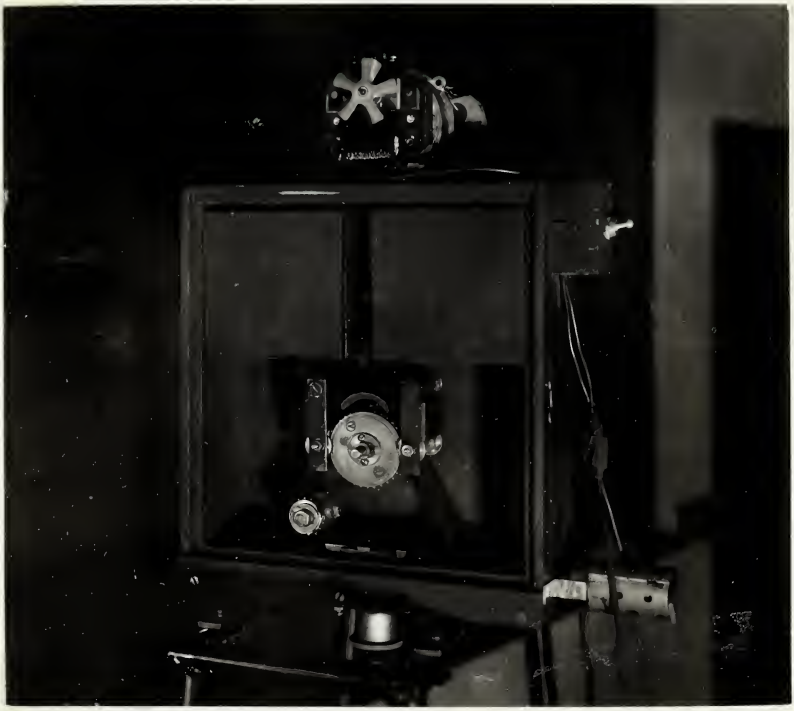


Plate 18

Camera

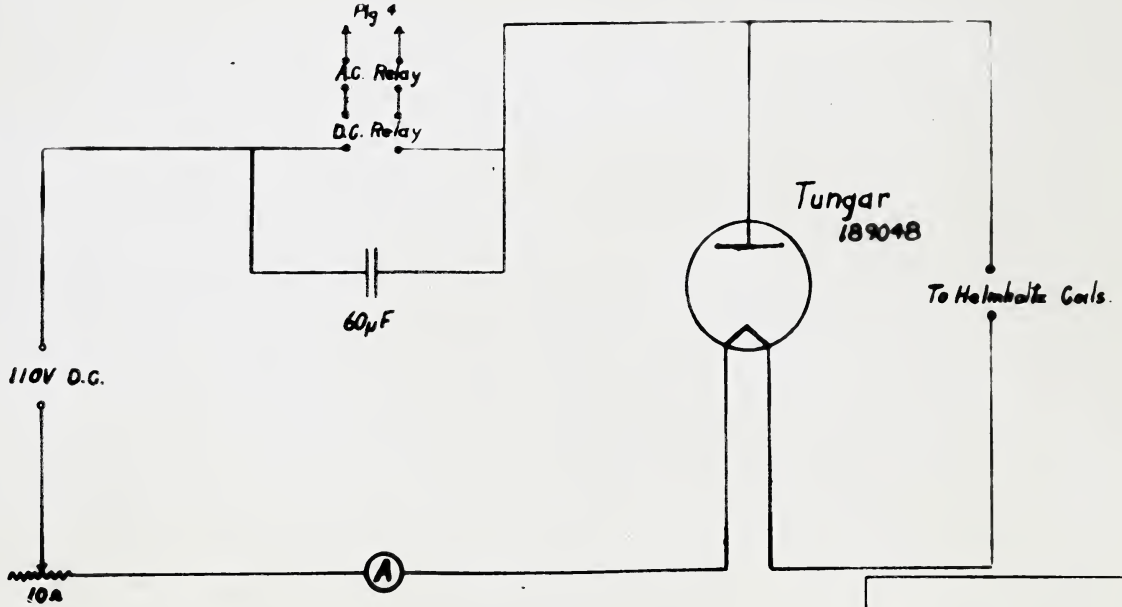


Fig. 1.
Helmholtz Coil
Circuit.

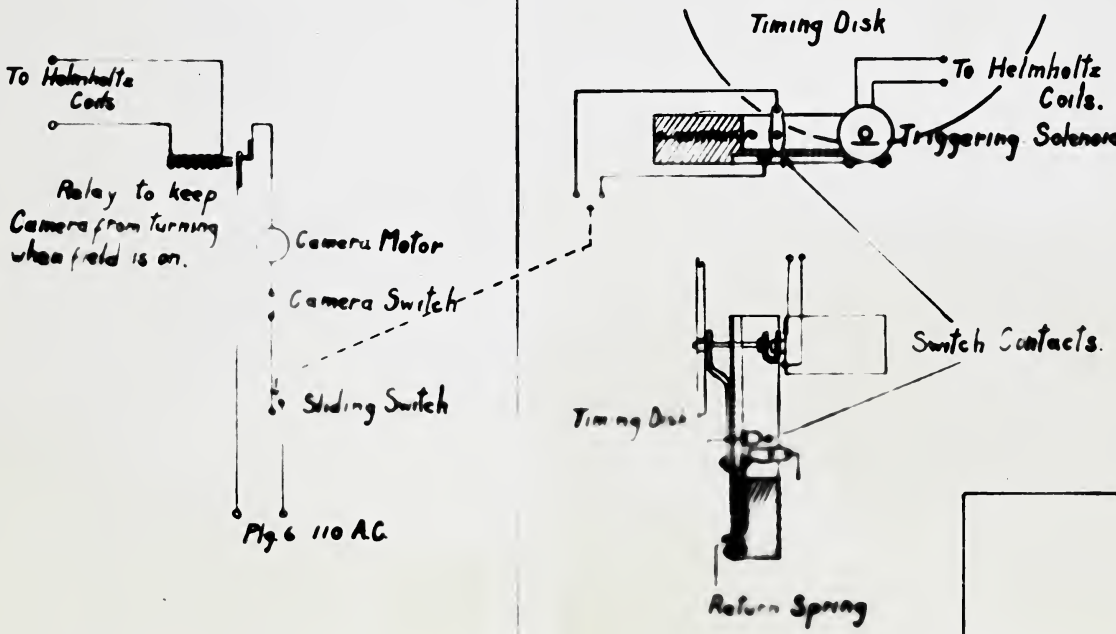


Fig. 2.
Camera Control Circuit.

lens using 35 m.m. perforated film. A pull away shutter keeps light out of the camera when a picture is not being taken. The shutter is actuated by a small electromagnet fastened to the Helmholtz coils circuit.

The camera is chain driven by a Flexo-action motor, 110 volts, 60 cycle, geared to 10 r.p.m., made by Merkle Korff Gear Co.. A toothed wheel engaging the film is fastened to a disc with four holes which are spaced one frame apart. These holes actuate a sliding switch (Fig. 2) which allows advance of the film one frame each time the Helmholtz coils are actuated.

The camera is mounted on an aluminum stand which is bolted to the top Helmholtz coil. Two front aluminized mirrors in frames at either side of the stand allow stereoscopic views of the chamber to be taken. The mirrors are 8-1/4" apart, extending down against the top of the chamber. Each mirror gives a view of one half of the chamber on the film.

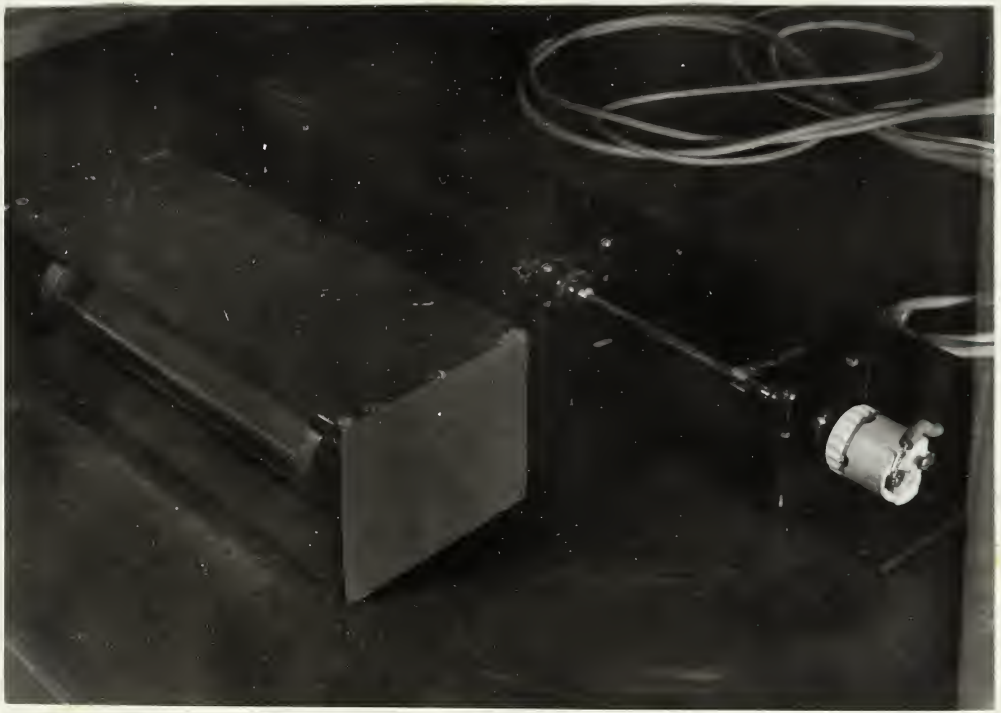


Plate 19 Flash tube holder and container showing lucite lens.

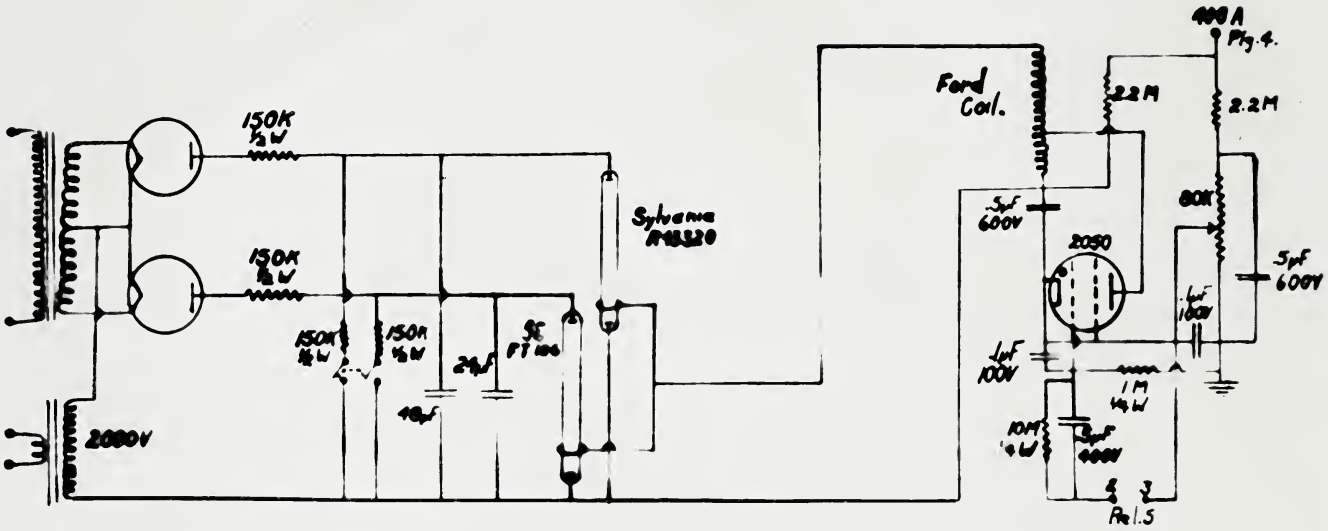


Fig. 3.
Lighting Circuit.

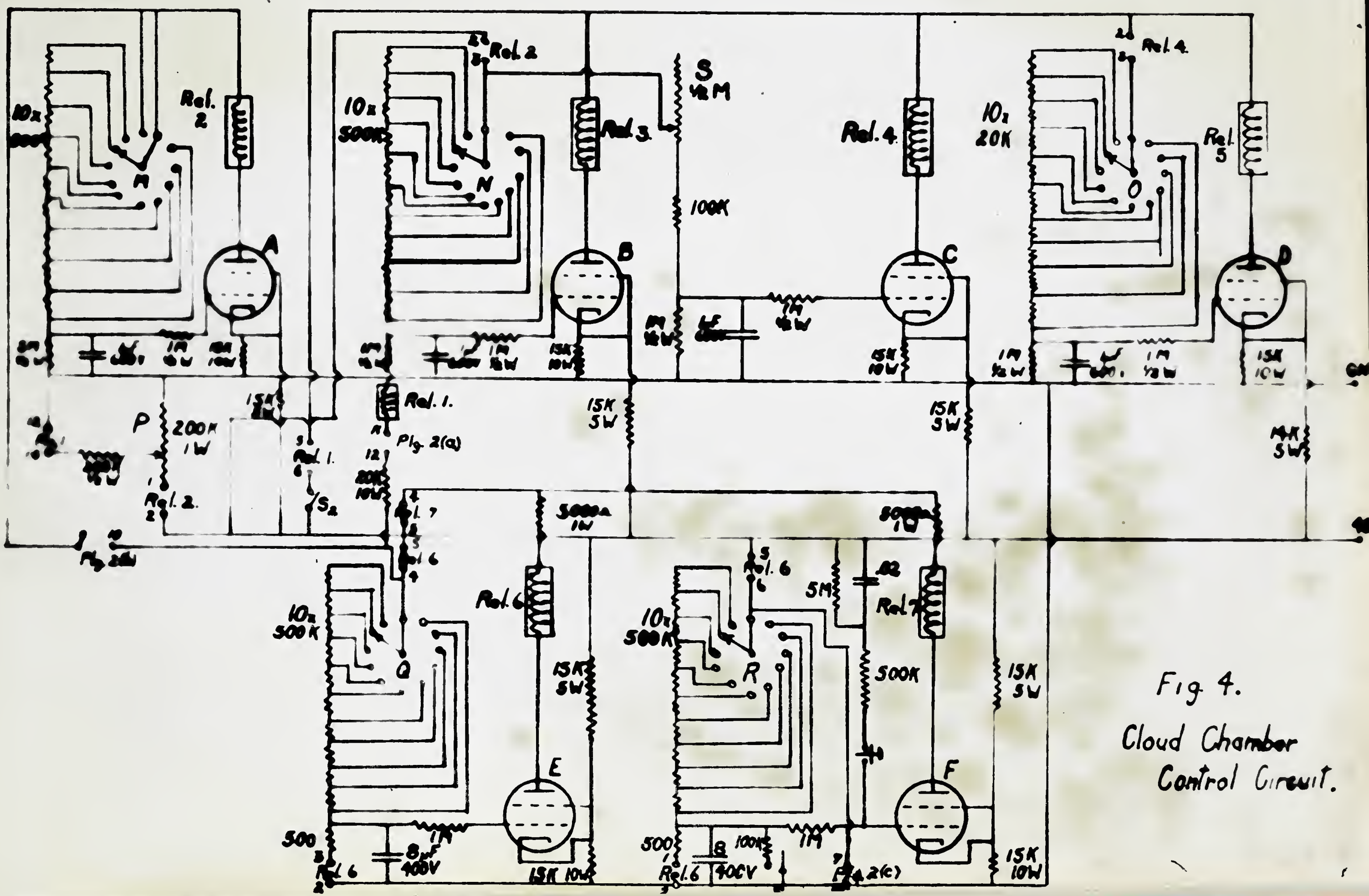


Fig 4.
Cloud Chamber Control Circuit.

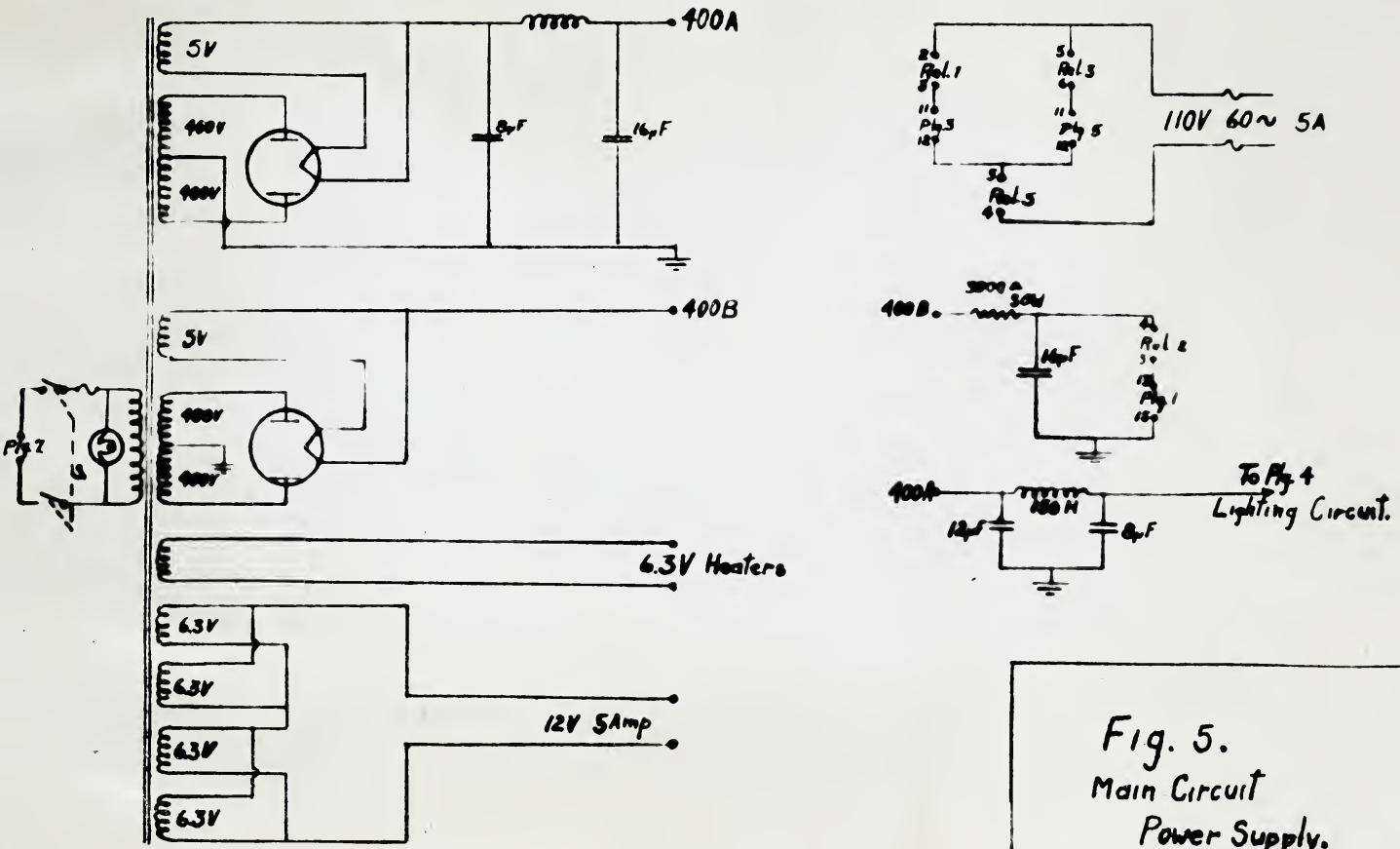


Fig. 5.
Main Circuit
Power Supply.

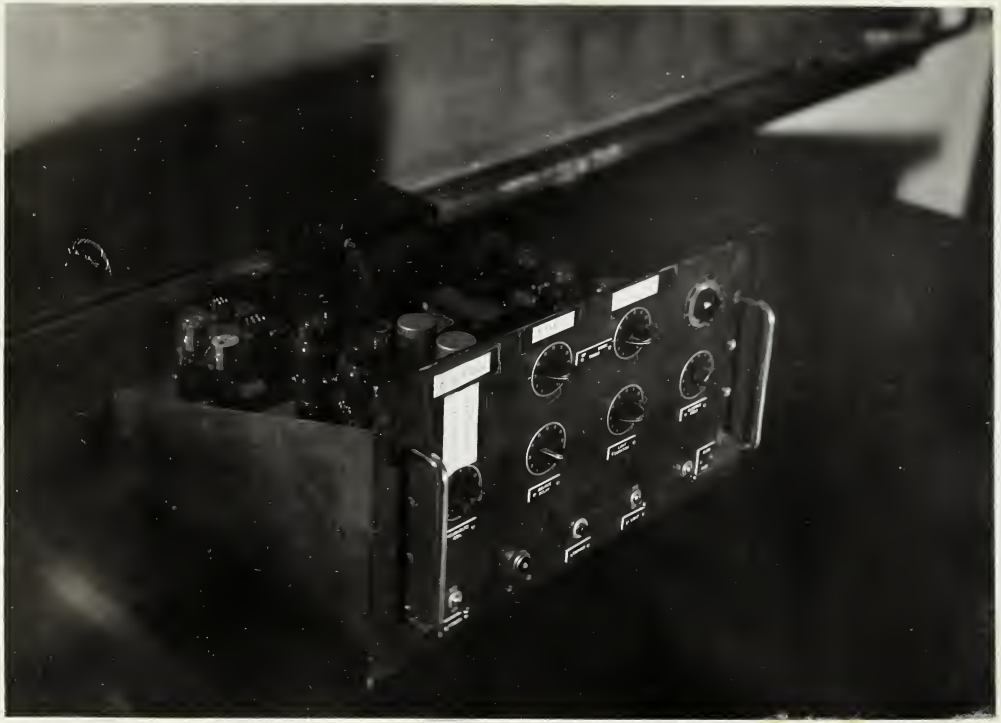


Plate 25 Main control circuit

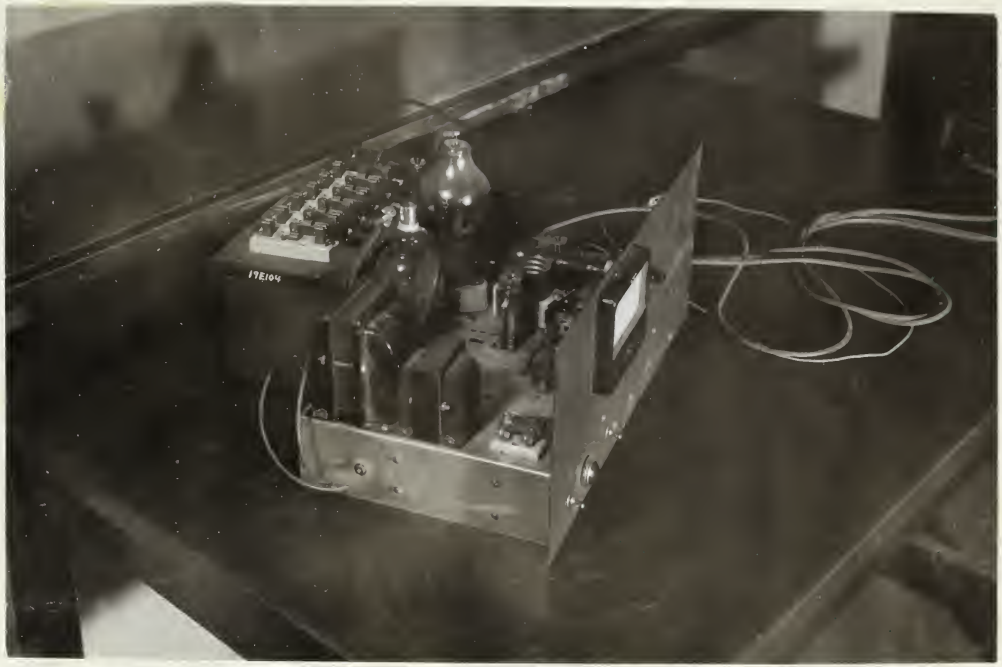


Plate 26 Automatic and flash control circuits

4. Illumination.

Illumination is accomplished by high speed Argon photoflash lamps of the straight tube type G. E. FT-126 mounted in boxes to fit between the coils (Plate 19). The back half of the tube is silvered to increase illumination. A clear lucite lens, made by splitting and polishing a 2" lucite rod, is used to collimate the beam. Two diametrically opposed lamps are used, each fired from a common trigger circuit, (Fig. 3) but with separate condensers.

5. Control Circuits.

(a) Description

The main control circuit was arranged as shown in Fig. 4 and Fig. 5 . It consists of a series of timing circuits. Each timing circuit uses a grid condenser type of control, in which the cathode of a thyratron is kept at a 400 volt positive value with respect to ground, the plate being at 400 volts. A condenser between the grid and ground is then charged up through a variable resistor network between it and the plate.

When the voltage on the grid has reached a sufficiently high value to exceed cutoff the thyratron fires, closing a relay in its plate circuit. This relay in turn closes the circuit to another thyratron or to some external mechanism such as the flash tube. Time delays are adjusted by varying the resistor network to the grid condenser.

The minor control circuit, or automatic operation circuit, consists of a 12 position selector switch triggered by a solenoid which is energized by one of the timing circuits in the main control circuit. There are actually 6 different positions on the selector switch, the other 6 being repetitions. This switch controls the automatic operation of the chamber, closing circuits to:

(A) Helmholtz coils

(B) Expansion circuit

(C) Lighting circuit

Paper condensers are used throughout, except in high voltage filters. The relays are made by

Clare and Co. and are type A4L31C with 18000 turns and resistance of 8100 ohms. The relays are a six terminal type plus two energizing terminals. 1 and 2, and 4 and 5 are normally closed; 2 and 3, and 5 and 6 are normally open.

There follows a list of items in the main circuit together with their functions. (Fig. 4 and Fig. 5)

Relay 1 - Switches 110V 60 W to plug 3.

Relay 2 - Switches 400 B to plug 1.
Cuts off 400 A to clearing field.

Relay 3 - Switches 110 V 60 W to plug 5.

Relay 4 - Not used.

Relay 5 - Closes lighting circuit.
Cuts off power to plugs 3 and 5.

Relay 6 - Controls operations of Relays 1 And 2 and 7. Relay 2 causes expansion and compression.

Relay 7 - Controls timing circuit of Relay 6.

Relays 6 and 7 control the main cycle of operation.

Plug (1) - 12 and 14 to clearing field.
13 and 15 to expansion valve on chamber.

Plug (2) - (a) To step switch for major expansions.

(b) To step switch for minor and major expansions.

(c) To step switch for stabilizing interval.

Plug (3) - (1-3) 6.3 V filament on thyratron on panel 2.

(2-4) Relay for Helmholtz coils.

Plug (4)- (1) 400 A for lighting circuit.

(2) Ground.

(3-4) To relay 5 for triggering light.

Plug (5) - Not used. To relay for source.

Plug (6) - 110 V 60 W to camera motor.

Plug (7) - 110 A.C. mains.

S_1 - Turns power on and off.

S_2 - Turns lighting and source on and off.

S_3 - Turns on slow or fast expansions.

Selector Switches-

H - Time delay for Helmholtz coils.

M - Time delay for source.

Plate 12

Tilting table with camera on stand for reprojecting track images.

and dust particles. In the circuit as used they are produced by causing an expansion to take place before full compression has occurred. This is done by regulating the length of the timing interval. The chamber remains compressed for 9.5 seconds and is expanded for 2.5 seconds and a full cycle of operation requires 72 seconds. Other satisfactory cycles may be set up by adjusting Q and R.

6. Tilting Table.

An 8" by 12" piece of glass, painted white was placed on top of the 12" by 12" bakelite table top, and used to view the tracks (Plate 12). The bakelite was fastened to a steel hemisphere which fits into a machined bowl, with an electromagnet in the middle that makes close contact with the hemisphere. The electromagnet clamps the hemisphere solidly at any angle. The table was limited to a ten degree tilt by means of an adjustable collar on the hemisphere. This limiting angle was calculated using the boundaries of the illumination at the lucite walls as determined experimentally. (Plates 12a, 13)

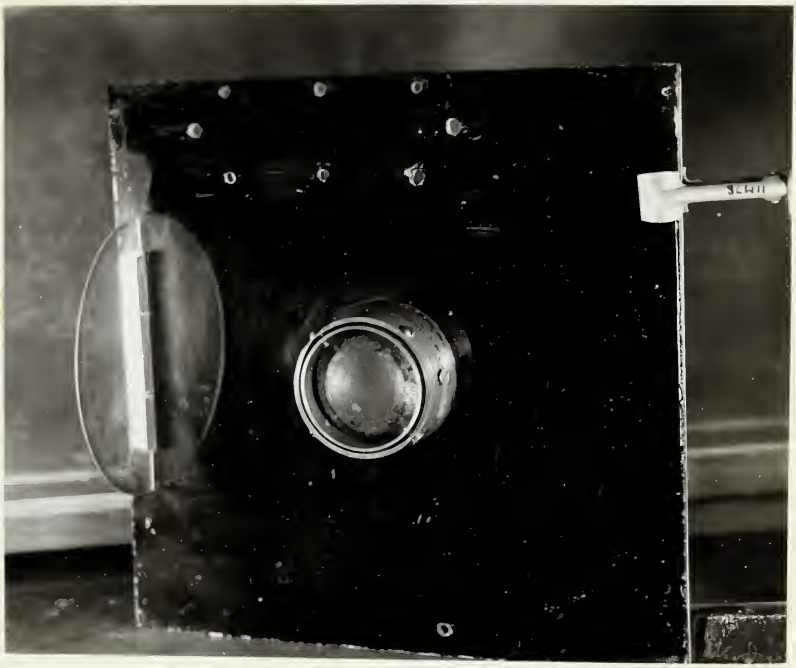
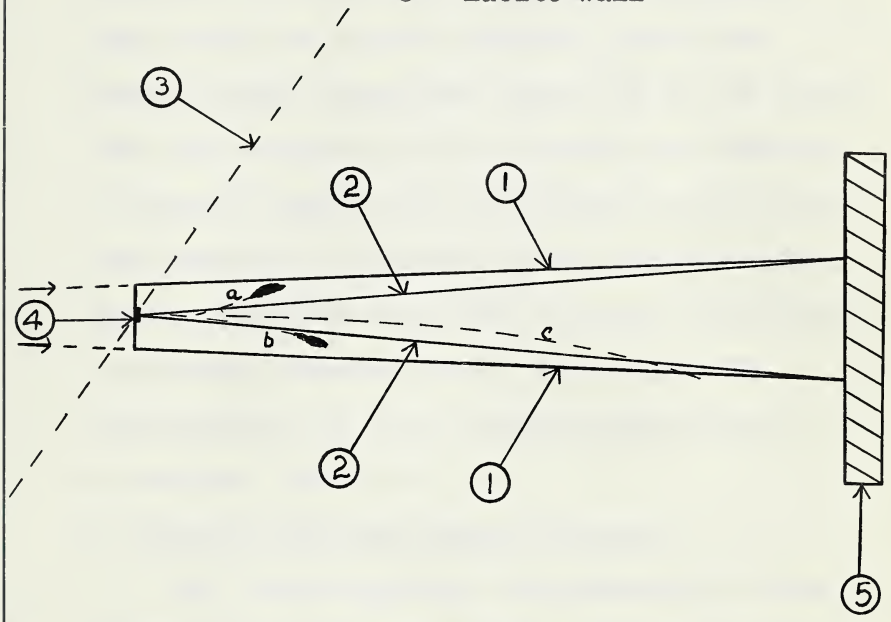


Plate 12a

Steel hemisphere with fixed and adjustable collar, in position on the bottom of the tilting table. This collar limited the tilting angle.

1 - Defined edge of light beam from flash tube
2 - Limited position of tilting table
3 - unlimited position of tilting table
4 - Source at center of chamber

5 - Lucite wall



Front view

Right half of chamber

Plate 13

7. Electrolysis Apparatus.

A U tube 2.5 cm. in diameter and 10 cm. on a side was used as a container for the solution of RaD and E. The anode and cathode were made from platinum discs two cm. in diameter, spot welded to #20 gauge platinum wire joined to a 1/4" diameter glass tube. Several small vanes were drawn out on the glass tube of the anode as it was used as a stirrer. A grooved, rubber disc was placed on the anode and driven by a variable speed electric motor. Mercury contacts were used for both electrodes. The circuit consisted of a dry cell, 0-100 microammeter and a one megohm potentiometer in series. (Plate 9)

8. Vinylite Film and Source Support.

The central hole in the perforated brass bottom of the chamber was tapped with a 6-32 tap, and a 6-32 flat headed bolt cut to prevent it cutting the rubber diaphragm. The head of the bolt was drilled and tapped with a #56 tap for which 1/8" copper rod was turned down and threaded.

A U-shaped piece of #18 gauge wire about 4 cm. in length, was soldered to the desired length of copper rod and this was the film support. The bolt was placed in the central hole, then the velveteen put in place and the copper rod with the film and source screwed into the head of the bolt.

9. Evacuating System.

This consisted of a Cenco Hyvac pump connected to the chamber through a drying tube, mercury manometer and a three way stop-cock. (Plate 15) The connection to the chamber was made at the top of the tube used to introduce the working mixture of water and alcohol. A vacuum-tight joint was used as a connection to this tube. The gas mixtures were introduced from two tanks connected by a three-way stop-cock at (A). (Plate 15). The working mixture was placed in the thistle tube prior to filling the chamber with the gases and then introduced by opening stop-cocks (1) and (2). (Plate 15).

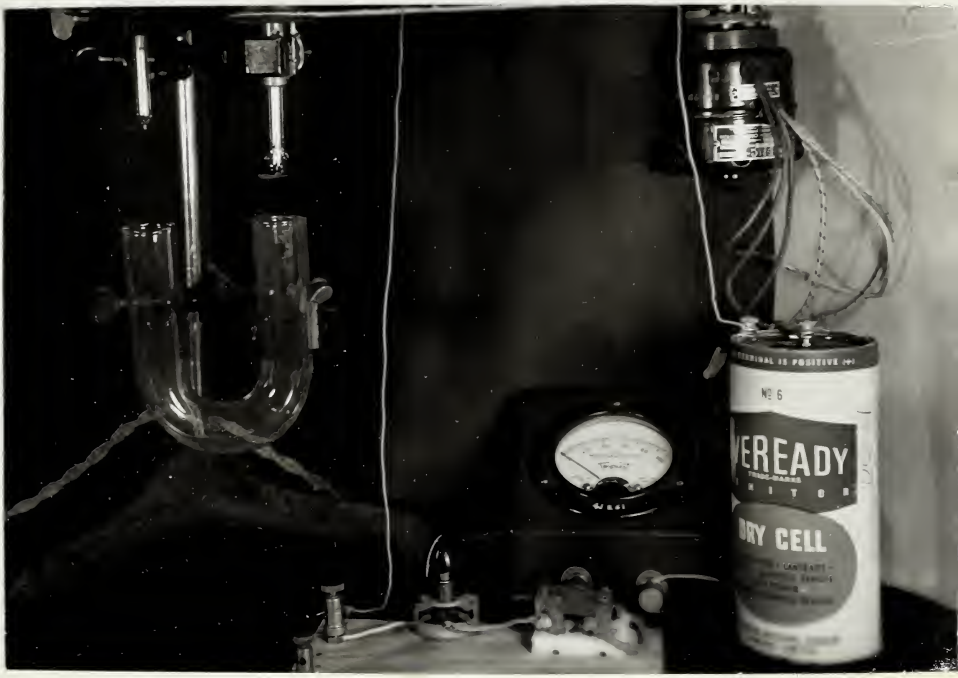


Plate 9

Electrolysis Apparatus

Plate 15

System for evacuating and filling chamber with different gases.

Plate 15a

Thistle tube and stop-cocks 1 and 2 for introducing working mixture.

Experimental Method

Preparation of RaE Source.

Although the source strengths handled were low, rubber gloves were used throughout. The method described here for the separation of RaE has been used at Oak Ridge.

An old radon seed was placed in the brass container and ground by means of a fitted brass rod (Plate 8). It was placed in 100 ml. of N/2 HCl and allowed to stand for one day before separation of the RaE, thus allowing time for the RaD, E and F to be dissolved.

A silver powder prepared by filing a three inch length of 16 gauge silver wire, was placed in a 250 ml. flask and the solution of RaE, E and F was poured into the flask. It was tightly corked and vigorously shaken for 10 minutes and then the solution was filtered to remove the silver powder. This procedure separated the RaF from RaE and D due to the chemical affinity of RaF for silver.

The resulting solution of RaD and E was

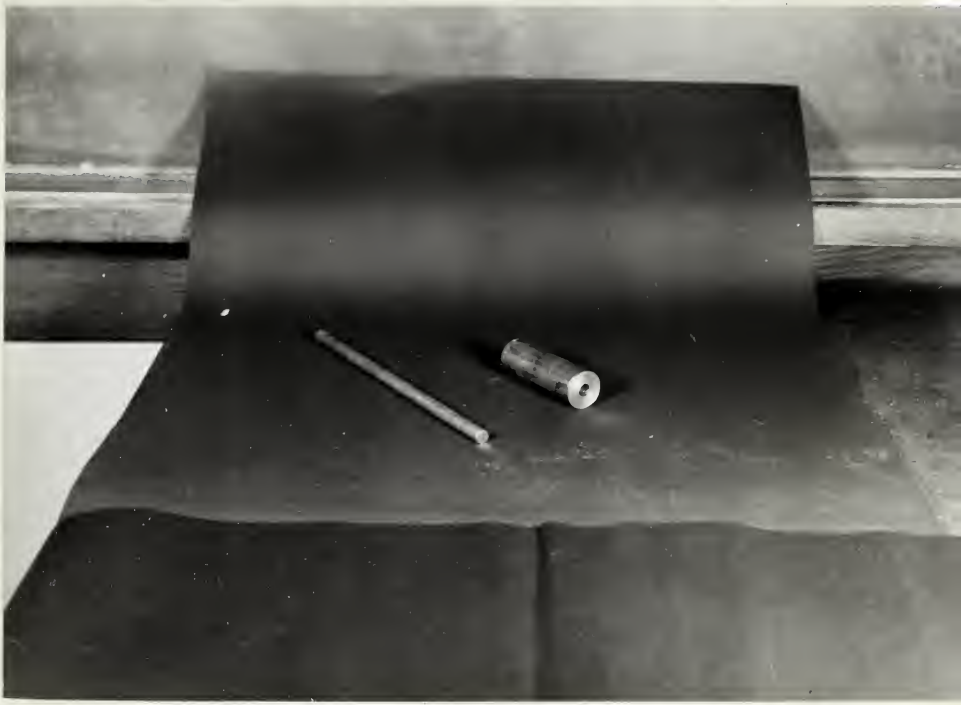


Plate 8

Container and rod for grinding radon seeds.

poured carefully into the U tube which was suitably held on a retort stand. (Plate 9). The U tube was moved up so that the platinum cathode and anode were submerged. Since the anode was used as a stirrer it was submerged about two inches. The stirrer was set in operation and the current adjusted by means of a potentiometer to 28 ua. This gave a current density of 10 ua/cm^2 at which value RaE begins to be deposited.(12)

The activity of the cathode was checked every 5 minutes using a scaler and associated circuits. (Plate 10). After 10 minutes the activity of the source was 6176 counts per minute on shelf No. 1. This was more than sufficient for the purpose of these experiments. A source of approximately 1500 counts per minute was required since our experience has shown that this activity will give between 10 and 15 tracks per major expansion. The required activity was dissolved off using N/2 HCl, the correct amount being determined by frequently checking the residual activity on the cathode. This solution was then evaporated to dryness,

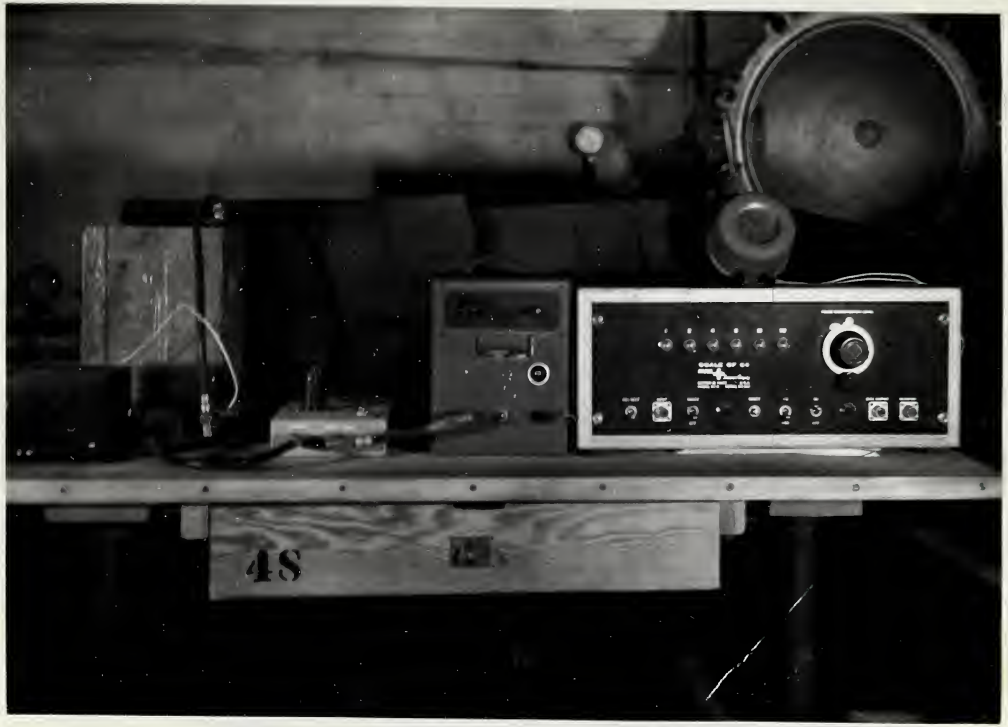


Plate 10 Scaler, lead castle and associated apparatus.

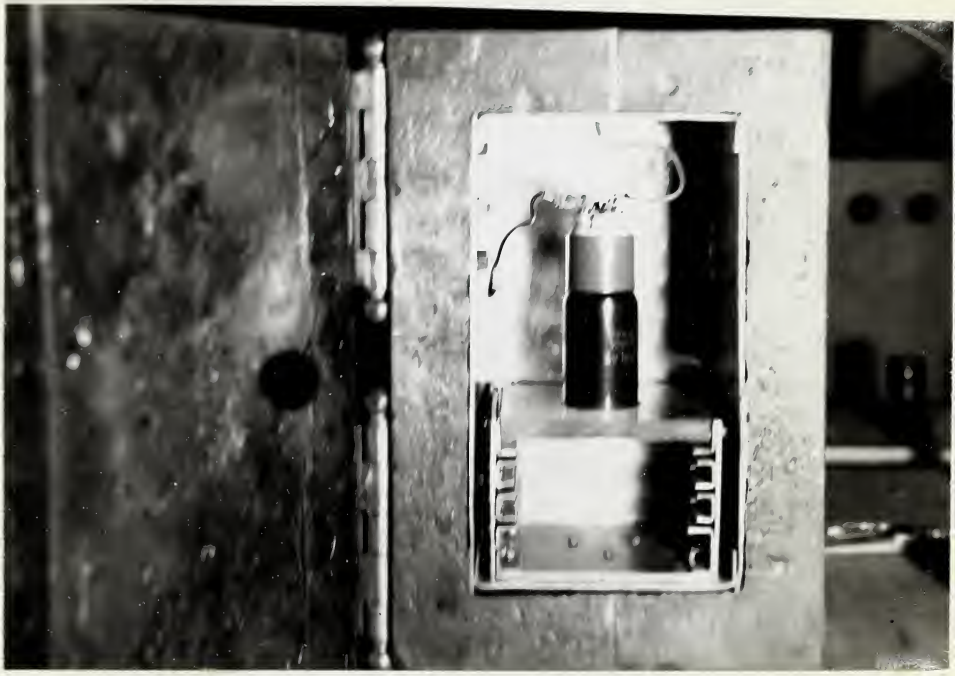


Plate 10a

Lead castle showing Geiger tube and trays.

using a bunsen burner and making certain that the last few drops to be evaporated were on a small area. Then one drop of N/2 HCl was added by means of a fine tipped eye dropper. The drop was moved about the tube with the eye dropper to assist it in dissolving the RaE. Then this drop was placed on a vinylite film mounted on the wire source-supports. The drop was evaporated using the heat from an ordinary desk lamp with a 60 watt bulb. The film was then checked for activity. If the value was too high some of the RaE was dissolved off by placing a drop of N/2 HCl on it and removing it again with the eye dropper. If the activity was too low more RaE was added.

Procedure using Cloud Chamber.

The source was placed centrally in the cloud chamber and stereoscopic photographs were taken of the beta particle tracks from the RaE in hydrogen, oxygen, and in two gas mixtures, namely 10 cm. of mercury pressure of oxygen and 60 cm. of hydrogen; and 22.5 cm. of oxygen and 47.5 cm. of hydrogen. By using these mixtures a reasonable

amount of overlapping of energies from the different ranges was obtained. A total of 435 frames were taken.

Before putting the gas in the chamber, the chamber was evacuated to 1 mm. of mercury pressure. Then it was flushed out and evacuated twice with the gas or gas mixture to be used, then evacuated and filled to atmospheric pressure as indicated on a mercury manometer. The temperature of the room was taken and recorded throughout the proceedings from a thermometer placed on the top Helmholtz coil. The barometric pressure was recorded four times during the procedure.

The film was tank developed for six minutes at 20 degrees centigrade using high contrast developer formula D-19 by Kodak.(Appendix 1). It was then fixed for eleven minutes using formula F-5. (Appendix 1).

Method of Measurement.

The camera and stand were removed from the chamber and placed in position on the tilting table(Apparatus). The lens to table distance was

made the same as the lens to source distance in the chamber. The developed film was replaced in the camera in the same position that it occupied when the photographs were taken and the tracks reprojected on to the white table top, by means of the projector lamp.(Plate 11). The source image was placed centrally on the levelled table top and the three views made to coincide as each frame was brought under the lamp. By tilting the table the three photographs of a given track could be made to coincide over most of the track length. Since care was taken to assure that the camera lens was not touched, the track image so obtained was a very close approximation to the original track in the cloud chamber. The track range was then measured by means of a divider. If the track was curved the divider was set at about three millimeters and the track length stepped off. The divider spacing was determined by the amount of curvature present. The tilting table was limited to a 10 degree tilt. Thus all tracks measured were within a 10 degree solid angle, which

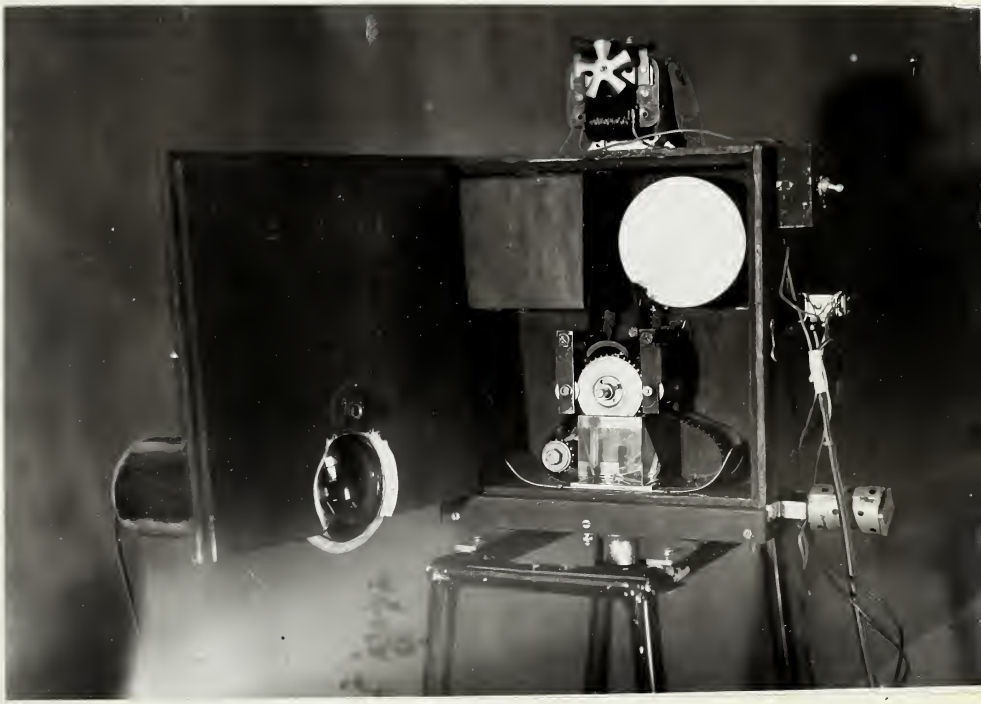


Plate 11

Camera showing reprojecting prism and light in position.

was just within the defined edges of the beam at the lucite walls. (Plate 13). Without this limit on the tilting angle a much larger solid angle was available to short tracks near the source (a and b Plate 13) but the longer tracks were still limited to this 10 degree solid angle by the boundaries of the light beam.(c Plate 13). This assisted in getting a more representative cross section of the spectrum. If a track appeared to end but the three photographs could not be made to coincide, the track was discarded. A weight between 1-5 was assigned to each track, depending on the clarity of origin and ending. The tracks in each frame were numbered, starting at one side of the source and going in a clock-wise direction. (Plate 14). This assisted in re-checking the measured tracks in the projector or on the tilting table. For the method of numbering the tracks see (Plate 14). All the tracks in each frame, except those considered as old tracks, were counted and recorded, which gave a normalizing factor,to use in combining the distributions from the various

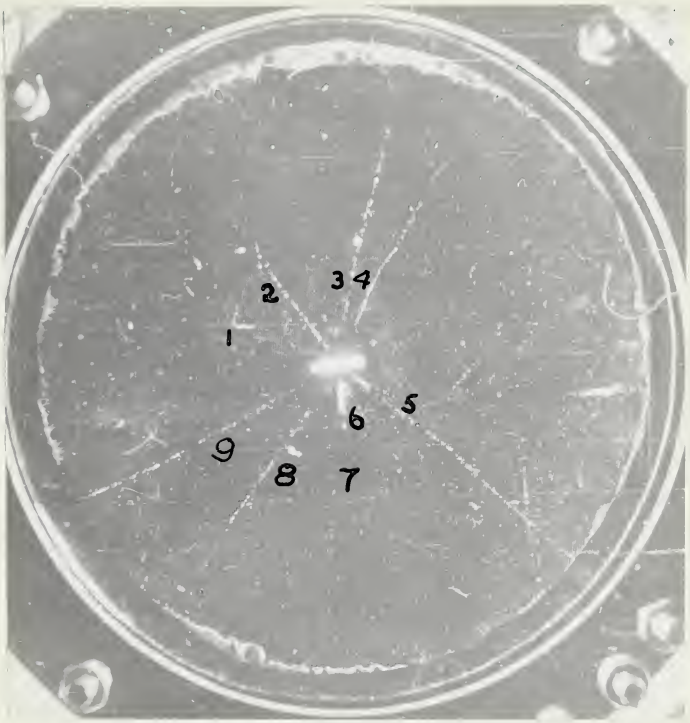


Plate 14

Method of numbering tracks.

gases and mixtures.

Plates 21 to 24 show the low energy tracks in the various gases and give an idea of the weighting process.* After all the tracks of one roll were measured they were re-examined in a projector where each of the three stereoscopic views could be examined separately. In this way an additional check on the certainty of origin and ending of the tracks was obtained.

The measured ranges were converted to energies using the two formulae:

(1) $E = 24330\left(\frac{n_1}{n_2} R\right)^{\frac{1}{2}}$ when hydrogen was used. (Thompson-Whiddington relation)

(2) $E = 24600\left(\frac{n_1}{n_2} R\right)^{0.55}$ for the remaining mixtures as the stopping power was due mainly to oxygen. (Williams) (14).

E = energy in electron volts.

n_1 = number of extra nuclear electrons per c.c. in the chamber at the end of the expansion.

n_2 = number of extra nuclear electrons per

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* The weighted tracks were not used so they were not illustrated on these plates.

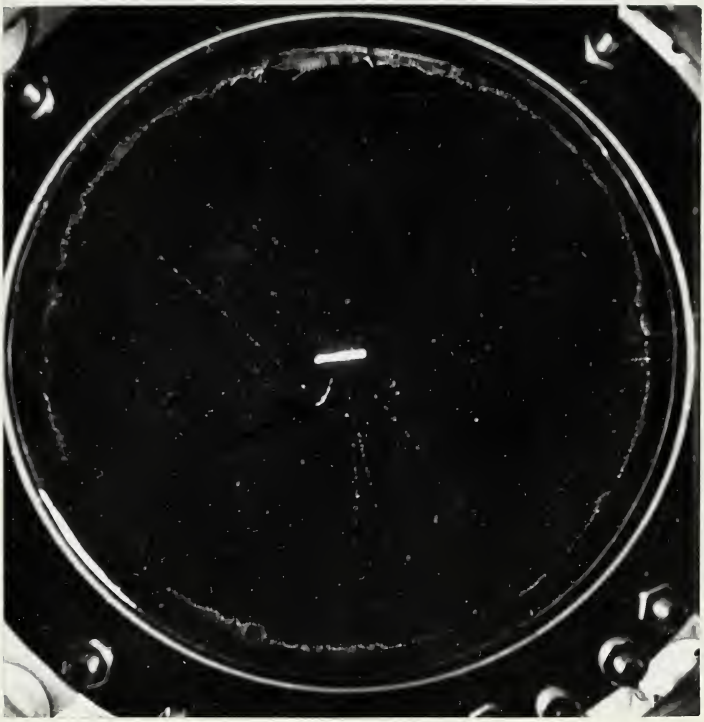


Plate 21

Low energy track in hydrogen (arrow)

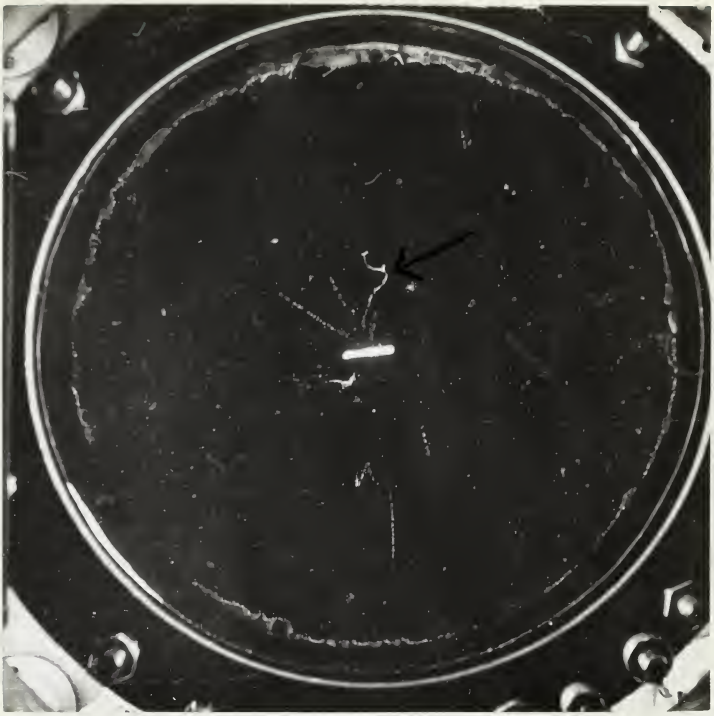


Plate 22

Low energy track in gas mixture of 10 cm.
mercury pressure of oxygen, 60 cm.
hydrogen (arrow)

Plate 28

Low energy track in gas mixture of 22.5 cm. mercury pressure of oxygen, 47.5 cm. hydrogen (arrow)

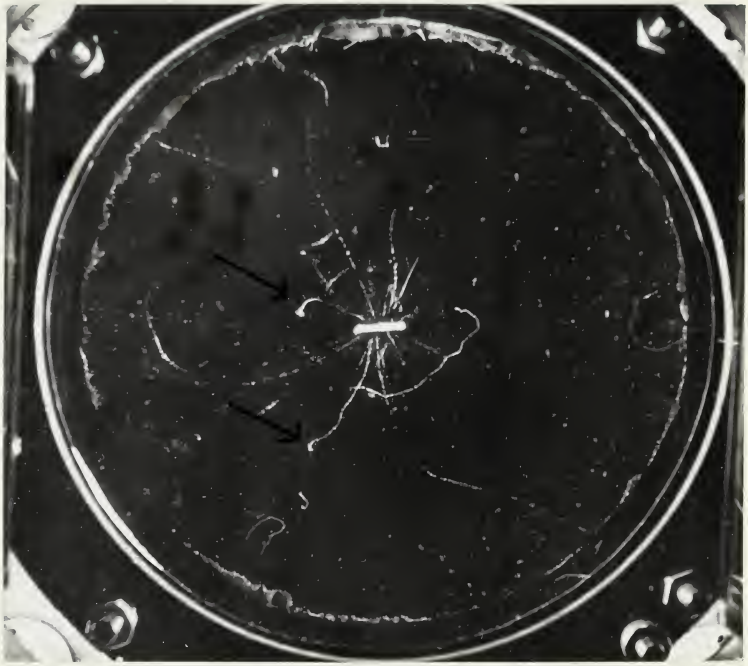


Plate 24

Low energy track in oxygen (arrow)

c.c. in oxygen at N. T. P.

R= measured range in cm.

Determination of the half-life of the source.

The source was removed from the chamber and fixed on the first tray, with an absorber of 7 mg/cm.^{2} to stop the alpha particles of RaF. The source activity was measured on a scaler at the same hour for several days. After forty to forty five days the activity became constant at about 20 cpm. above background. This was attributed to RaD. Logarithms of the corrected cpm. were plotted against the time and the half-life of the decaying substance calculated.

Observations

Roll NO.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2}R)^{\frac{1}{2}}$	Energy Kev.
1	1		8			
H_2	2		6			
	3	4	7	2.2	0.37	9.0
	4		6			
	5	6	6	3.4	0.46	11
	6		6			
	7	7	7	1.5	0.31	7.5
	8		8			
	9	1	8	9.2	0.76	18
	10		5			
	11		6			
	12		6			
	13		10			
	14		5			
	15	4	9	5.4	0.59	14
		10		1.3	0.29	7.0
	16	1	5	1.4	0.30	7.3
	17		10			
	18	1	6	1.5	0.31	7.5
		4		4.5	0.53	13

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2}R)^{\frac{1}{2}}$	Energy Kev.
	19		5			
	20	6	10	4.0	0.50	12
	21		2			
	22		8			
	23		8			
	24		5			
	25	1	10	8.8	0.75	18
		2		3.7	0.48	12
	26		7			
	27		7			
	28		7			
	29		3			
	30		5			
	31		4			
	32		5			
	33	1	5	4.5	0.53	13
2 H_2	1	3	7	1.8	0.34	8.3
	2	6	6	7.6	0.69	18
	3		3			
	4		3			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2}R)^{\frac{1}{2}}$	Energy Kev.
3	1		8			
H_2	2		6			
	3	1	4	2.1	0.36	8.8
	4		5			
	5		7			
	6	3	7	9.3	0.77	19
		4		4.2	0.52	13
	7		7			
	8	1	6	1.1	0.37	6.5
		5		3.0	0.44	11
	9		7			
	10	5	6	5.1	0.57	14
	11	2	7	4.2	0.52	13
	12	5	10	9.0	0.75	18
	13		4			
	14		7			
	15		9			
	16	4	6	4.2	0.52	13
	17	7	8	1.5	0.31	7.5
	18	6	8	1.0	0.25	6.1
	19	1	5	6.5	0.64	16

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2}R\theta^2)^{\frac{1}{2}}$	Energy Kev.
	20		7			
	21		7			
	22	3	7	1.8	0.34	8.3
	23		7			
4	1		4			
H_2	2		8			
	3		4			
	4		4			
	5	9	9	5.0	0.57	14
	6	4	8	8.0	0.71	17
	7		9			
	8	4	4	3.0	0.44	11
	9	9	9	2.0	0.36	8.8
	10		6			
	11		5			
	12		6			
	13		6			
	14		6			
	15		7			
	16	5	9	1.5	0.30	7.3
	17		6			
	18	3	9	3.7	0.48	12
	19		8			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$\left(\frac{n_1}{n_2}\right)_R^{\frac{1}{2}}$	Energy Kev.
	20		6			
	21		10			
	22		6			
	23		10			
	24		8			
	25		8			
	26		3			
	27		2			
	28	8	8	3.2	0.45	11
	29		4			
	30		5			
	31	2	6	2.0	0.36	8.8
	32		5			
	33		7			
	34		7			
	35	6	6	6.0	0.62	15
	36		7			
	37	2	8	1.5	0.30	7.3
5	1		8			
H_2	2		3			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2}R)^{\frac{1}{2}}$	Energy Kev.
	3	3	12	2.0	0.36	8.8
	4		5			
	5	5	5	2.5	0.40	9.7
	6		7			
	7		3			
	8		4			
	9		5			
	10		7			
	11	3	4	2.7	0.41	10
	12		7			
	13	4	12	5.0	0.57	14
	14	2	6	3.5	0.47	11
	15		5			
	16		5			
	17		9			
	18		9			
	19		7			
	20		6			
	21		7			
	22		7			
	23		4			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2})^{\frac{1}{2}}$	Energy Kev.
	24		8			
	25	9	12	4.4	0.53	13
	26		5			
	27	4	12	1.7	0.33	8.0
6	1		7		$(\frac{n_1}{n_2})^{0.55}$	
Gas O_2	2	11	14	1.7	1.1	27
	3		15			
	4		9			
	5	4	10	7.5	2.4	59
	6	2	9	7.8	2.4	59
		3		7.1	2.3	57
	7		8			
	8	2	11	1.4	0.9	22
	9	1	9	14.9	3.4	83
	10	4	9	7.2	2.4	59
		7		1.9	1.1	27
		8		3.1	1.5	37
		12		2.8	1.4	34
	11	1	9	3.1	1.5	37
		11		4.9	1.9	47
	12		9			
	13		8			

Roll No.	Frame	Track	Total tracks	Range R(cm.)	$(\frac{n_1}{n_2})^{0.55}$	Energy Kev.
	14		5			
	15		10			
	16	12	9	3.3	1.5	37
	17	1	10	5.0	1.9	47
		5		3.5	1.6	40
	18		9			
	19		13			
	20	3	10	9.6	2.7	67
		8		7.6	2.4	59
	21	4	12	3.9	1.7	42
		7		8.3	2.5	62
	22	4	12	3.9	1.7	42
		6		1.1	0.8	20
		7		7.2	2.4	59
	23	8	9	5.0	1.9	47
	24	4	11	5.6	2.1	52
	25		12			
	26	3	11	8.4	2.6	64
	27	3	11	2.3	1.2	30
	28	3	11	4.3	1.8	44
	29	3	9	5.5	2.0	49

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2}R)^{0.55}$	Energy Kev.
	30	6	8	3.6	1.6	40
	31	6	10	9.6	2.7	67
	32	7	9	8.5	2.6	64
	33	4	9	7.4	2.4	59
		5		5.1	1.9	47
	34	2	6	8.0	2.5	62
		9		8.4	2.6	64
	35	7	9	2.9	1.4	35
	36		9			
	37		7			
	38	3	6	6.5	2.2	54
7	1	4	14	1.8	1.1	27
O_2	2	4	7	5.9	2.1	52
	3	12	13	4.9	1.9	47
	4		11			
	5		14			
	6	2	10	8.7	2.6	64
		5		1.5	1.0	25
	7		10			
	8		16			
	9		10			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1 R}{n_2})^{0.55}$	Energy Kev.
	10	3	8	3.0	1.5	37
	11		11			
	12		10			
	13		11			
	14	10	12	5.1	1.9	47
	15	1	7	4.4	1.8	44
	16	3	12	3.2	1.5	37
		5		6.4	2.2	54
	17		10			
	18	6	8	1.5	1.0	25
	19		10			
	20		11			
	21		8			
	22	2	9	7.0	2.3	57
		7		4.7	1.9	47
		9		6.3	2.2	54
	23	9	10	2.5	1.3	32
	24		8			
	25	9	15	6.9	2.3	57
	26	5	10	5.0	1.9	47
	27		11			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(n_1 R)^{0.55}$ / n_2	Energy Kev.
8	1		8			
O_2	2		12			
	3		12			
	4		10			
	5	5	9	3.3	1.5	37
	6		9			
	7		10			
	8		11			
	9		7			
	10	3	10	6.0	2.1	52
	11		8			
	12		9			
	13	12	14	2.6	1.3	32
	14	10	12	5.0	1.9	47
	15		8			
	16	10	13	5.4	2.0	49
	17	4	13	1.9	1.1	27
		6	13	11.5	3.0	74
	18		15			
	19		12			
	20		12			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2})^{0.55}$	Energy kev.
	21	2	9	4.0	1.7	42
		5		3.3	1.6	37
	22		7			
	23		6			
	24		9			
	25		12			
	26	1	9	3.3	1.7	42
	27	2	10	8.1	2.6	64
	28	9	9	3.6	1.6	49
	29		4			
	30		4			
	31	2	10	3.3	1.7	42
	32	Double Exposure				
	33		10			
	34		5			
	35		9			
	36		8			
	37		9			
9	1		9			
O_2	2		6			
	3		8	3.8	1.7	42

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1 n}{n_2})^{0.66}$	Energy Kev.
	4		4			
	5		4			
	6		5			
	7		8			
	8	Double Exposure				
	9		7			
	10		8			
	11	4	8	3.2	1.5	37
	12		8			
	13		9			
	14		8			
	15		10			
	16	7	8	5.3	2.0	49
	17		7			
	18		11			
	19		8			
	20		7			
	21	4	10	6.0	2.1	52
	22		7			
	23		7			
	24		7			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2}R)^{0.55}$	Energy Kev.
	25		5			
	26		5			
	27		6			
	28		4			
	29		8			
	30		7			
	31		7			
	32		7			
	33		4			
	34		7			
	35	2	7	2.8	1.4	35
		7		3.0	1.4	35
10	1		5			
Gas	2		6			
10cm. O_2 60cm. H_2	3	2	9	4.6	0.88	22
(cm. of		9		5.2	0.94	23
Mercury Pressure)	4	7	9	3.7	0.77	19
	5		8			
	6		7			
	7		9			
	8		6			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(n_{L_p})^{0.55}$ n_2	Energy Kev.
	9		7			
	10		9			
	11	4	11	2.6	0.63	16
	12	1	7	1.1	0.40	9.8
	13		6			
	14		5			
	15	5	5	1.8	0.59	13
	16	3	6	7.9	1.2	30
	17	3	5	5.4	0.96	24
		4		8.3	1.2	30
	18		7			
	19		9			
	20	1	6	6.5	1.1	27
		2		1.5	0.48	12
	21	6	6	7.0	1.4	35
		1		2.0	0.56	14
	22	2	9	3.0	0.69	17
	23		7			
	24	Double Exposure				
	25	5	6	8.1	1.2	30
	26	2	10	3.7	0.77	19

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_\lambda})^{0.55}$	Energy Kev.
11	1		9			
Gas	2	7	8	5.9	1.0	25
10cm. O_2 60cm. H_2	3	1	7	4.3	0.84	21
	4		8			
	5		6			
	6		7			
	7		6			
	8	1	4	9.0	1.3	32
	9	6	9	2.6	0.64	16
	10	Double Exposure				
	11		5			
	12	Double Exposure				
	13					
	14		6			
	15	6	6	2.4	0.47	12
	16		5			
	17		4			
	18	8	6	5.9	1.0	25
	19		5			
	20	5	6	2.5	0.62	15
	21		7			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{E_{1H}}{n_2})^{0.56}$	Energy Kev.
	22		9			
	23	Double Exposure				
	24		7			
	25		7			
	26	3	7	4.6	0.88	28
	27	1	6	4.8	0.90	32
	28	5	8	3.3	0.73	18
	29		6			
	30	1	5	3.6	0.76	19
		6		4.2	0.83	21
	31	3	6	2.8	0.68	14
		6		7.0	1.1	27
	32		5			
	33		6			
	34	2	9	4.1	0.82	20
	35		8			
	36		8			
	37	7	7	4.4	0.85	21
	38		6			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2})^{0.56}$	Energy Mev.
12	1		3			
Gas 10cm. O_2 60cm. H_2	2		3			
	3		6			
	4		4			
	5		5			
	6		6			
	7		5			
	8		3			
	9	2	5	2.7	0.66	10
	10		4			
	12		7			
	12		4			
	13	3	6	5.2	0.93	23
	14		3			
	15		4			
	16		4			
	17		4			
	18		5			
	19		3			
	20		4			
	21	Double Exposure				

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_1}{n_2})^{0.55}$	Energy Kev.
	22	2	3	1.8	0.63	13
	23		5			
	24	1	7	7.3	1.1	27
	25		7			
	26		8			
	27		7			
Gas 22.5cm. O_2 47.5cm. H_2	28	4	6	5.5	1.3	32
		6		3.0	0.89	22
	29		5			
	30		5			
	31		5			
	32		4			
	33		8			
	34	2	4	6.3	1.3	32
13	1		7			
Gas 22.5cm. O_2 47.5cm. H_2	2		4			
	3		8			
	4		4			
	5		6			
	6		6			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(n_1R)^{0.55}/n_2$	Energy kev.
	7	4	6	1.9	0.87	21
	8	1	4	7.3	1.5	37
	9		4			
	10		4			
	11		5			
	12		4			
	13		4			
	14	4	4	7.2	1.9	47
	15		5			
	16		4			
	17		4			
	18	2	4	5.0	1.2	30
	19	4	5	1.8	0.68	17
	20		3			
	21		4			
	22		2			
	23		4			
	24		4			
	25	1	6	2.8	0.86	21
		6		9.8	1.7	42
	26	7	6	4.2	1.1	27

Foil No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{R_{O_2}}{R_{N_2}})^{0.56}$	Energy Mev.
	27		4			
	28	1	6	4.8	1.1	27
	29	3	7	1.8	0.63	16
	30	5	6	3.0	0.89	22
	31	1	7	3.4	0.96	24
	32	1	5	2.4	0.79	19
	33		5			
	34		2			
	35	5	4	5.6	1.3	32
	36	4	4	2.2	0.75	18
	37	2	6	2.1	0.73	18
	38	9	6	1.4	0.59	15
	39		6			
	40	Double Exposure				
14	1		10			
Gas	2		9			
22.5cm. O_2 47.5cm. N_2	3	4	5	1.9	0.69	17
	4	1	7	2.3	0.76	19
	5	4	5	2.8	0.86	21
	6		7			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(L_1R)^{0.5}$ R_λ	Energy Mev.
	7		8			
	8		7			
	9	10	11	8.0	1.6	30
	10		8			
	11		6			
	12		6			
	13		6			
	14		6			
	15		6			
	16	5	11	8.0	1.6	37
		3		9.7	1.7	42
		8		10.0	1.7	42
	17	Double Exposures				
	18					
	19	1	6	9.0	1.6	40
		2		3.7	1.0	25
	20		10			
	21	2	6	1.7	0.65	16
	22		10			
	23	2	9	1.3	0.56	14
	24		8			

Roll No.	Frame	Track	Total Tracks	Range R(cm.)	$(\frac{n_{H_2}}{n_2})^{0.45}$	Energy Mev.
	25		6			
	26		5			
	27		6			
	28		9			
	29					
	30	Double Exposures				
	31		3			
	32		9			
	33	4	11	9.6	1.7	42
	34		6			
	35		6			
	36		6			

Measurement of source activity

Tube voltage ---------- 1425 volts

Discriminator setting -- 2 (positive side)

Background ---------- 30 cpm.

Absorber ---------- 7 mg./cm^2 of aluminum

Date	Time	Average 2-5min. counts	cpm.	cpm corrected for bkgd. and RaD.
Feb.13	11:30	3842	1169	1123
14	11:30	3114	1023	977
15	"	4490	898	852
16	"	3798	760	714
17	"	3374	675	629
18	"	2967	593	547
19	"	2511	502	456
20	"	2286	457	411
21	"	1968	394	348
22	"	1862	372	326
23	"	1650	330	284
25	"	1310	262	216
27	"	1082	216	170

Date	Time	Average 2-5 min. counts	cpm.	cpm. corrected for bkgd. and RaD.
Mar. 1	11:30	848	170	124
3	"	780	156	110
5	"	600	120	74
7	"	521	104	58
10	"	385	77	31
20	"	295	59	13
25	"	245	49	3
27	"	252	50	4
29	"	1512 (½hr.)	51	5
31	"	1405 "	49	3
Apr. 4	"	1472 "	49	3

Experimental Results

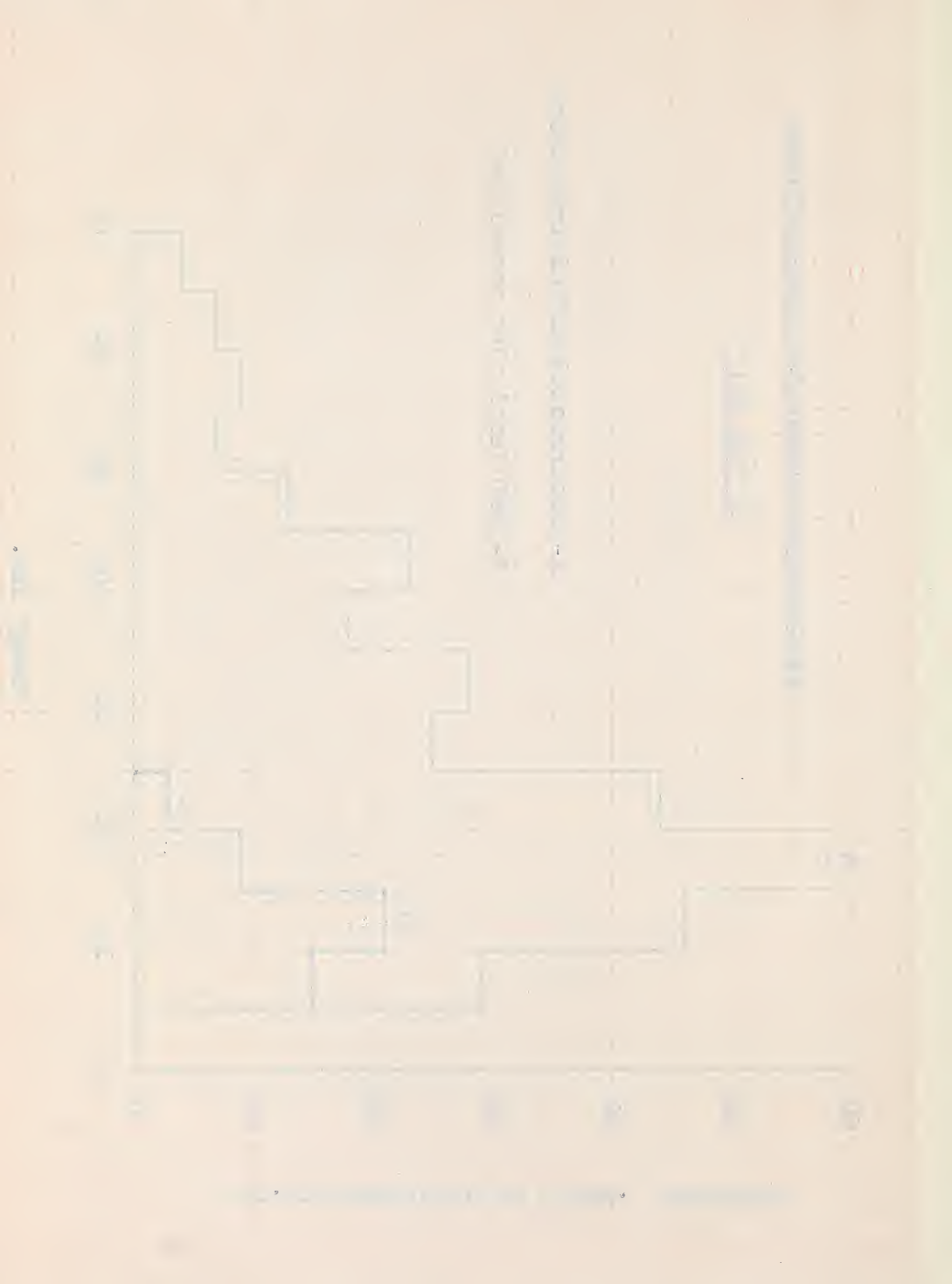
From graph 5, corrected for RaD, a half life of 5.1 days was calculated for the decaying substance. This agrees well with the accepted value for RaE of 5.0 days.(2)

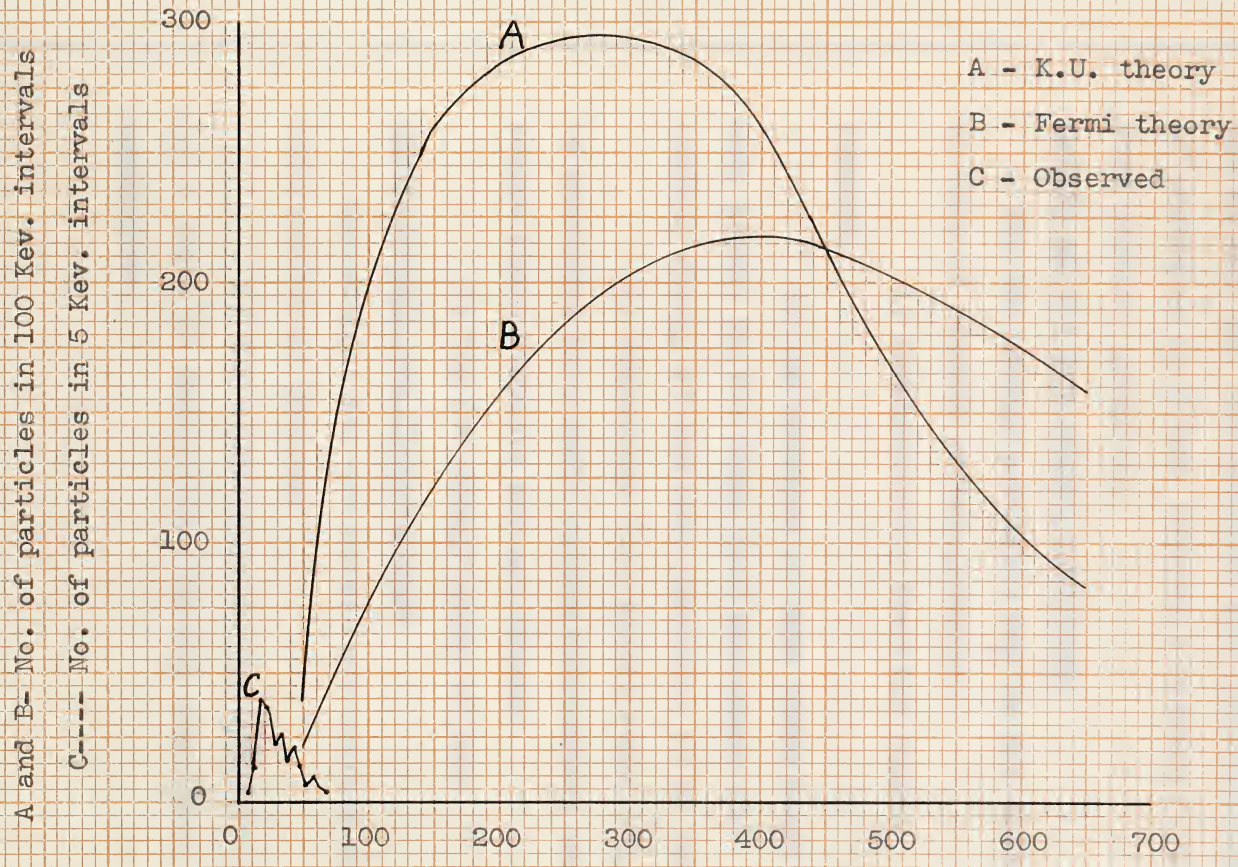
The distributions for the various gases and mixtures as calculated were plotted on graph 1. Then the distribution of each gas was raised to make it equivalent to 1250 disintegration, (the number of disintegrations counted in the oxygen series), and the resulting frequency distribution was plotted. (graph 2). The maximum occurring between 15-20 Kev. is quite evident, but the peak at 55 Kev., reported by Richardson (1) was not found.

The distributions as given by the Fermi and K. U. theories were calculated and normalized using the total number of measurable tracks as representing the complete RaE spectrum. These results along with the observed data, corrected for the presence of RaD and branching, were plotted (graph 3), and indicate the relative

Distributions in gas mixtures

Graph 1




A and B- No. of particles in 100 Kev. intervals
C---- No. of particles in 5 Kev. intervals
300
200
100
0
A
B
C
A - K.U. theory
B - Fermi theory
C - Observed
0
100
200
300
400
500
600
700
Energy Kev.

Graph 3

height of the observed maximum and the theoretical one at 400 Kev. The observed and expected number of particles in 5 Kev. intervals between 0-70 Kev. were plotted (graph 4).

Origin of the low energy particles.

The low energy particles may be due to one or more of several effects, namely:

1) Backscattering from the source support.

2) The presence of RaD. These would only appear in the range 0-25 Kev. since the maximum energy of RaD beta particles is 25 Kev.

3) Branching. This effect would only be unnoticed in a small volume surrounding the source where droplets are not formed.

4) The low energy group of RaE.

Corrections to the distribution.

Corrections for the above were applied to the distribution as follows:

1) The source support was approximately 0.3 u thick so back-scattering was considered negligible.

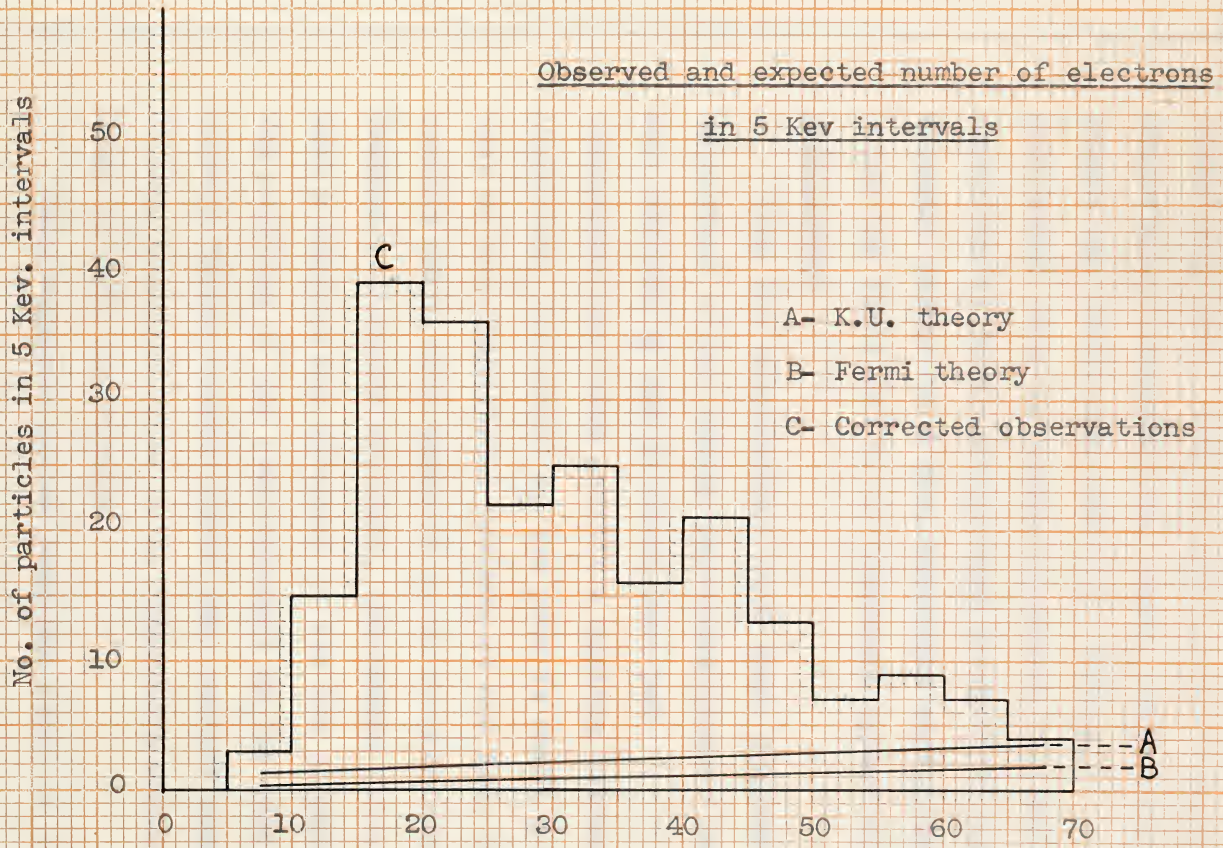
2) The activity measurements of the source indicated that 1.4% of the total count was due to RaD. On this basis the energy distribution according to the Fermi theory was calculated and normalized for the RaD spectrum and plotted. (graph 2). The ordinates of this curve were then subtracted from the histogram of the observed data.

3) Williams and Terroux (15) using oxygen in the cloud chamber observed 18 branch tracks between 7.5-10 Kev.; 33 between 10-20 Kev.; and 13 between 20-40 Kev. for a total track length of 1800 cm.

For a distance of 0.5 cm. on either side of the source no track droplets were formed because in this region the expansion is not adiabatic. Low energy branch tracks formed in this region would therefore be erroneously counted as disintegration tracks. An estimate of the number of these tracks from 5-10 Kev. is

$$\frac{0.5}{1800} \times 2230 \text{ (total number of tracks counted) } \times 18$$
in oxygen and mixtures.

and similarly for the other two ranges 10-20 and


Observed and expected number of electrons
in 5 Kev intervals
A- K.U. theory
B- Fermi theory
C- Corrected observations
No. of particles in 5 Kev. intervals
0
10
20
30
40
50
60
70
C
A
B
Energy Kev.

Graph 4

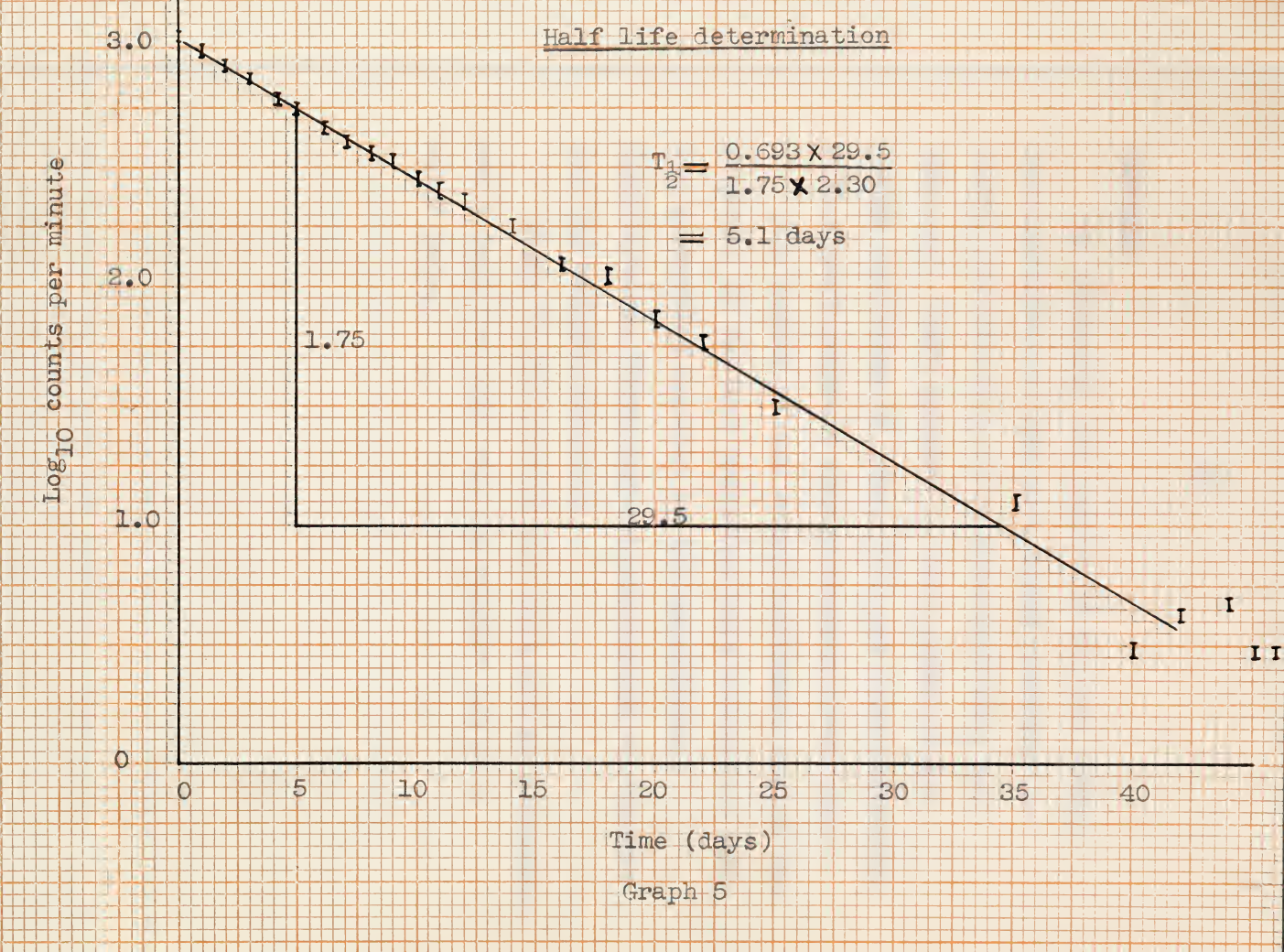
20-40 Kev. These numbers, assumed to be uniformly distributed throughout the energy ranges 5-10: 10-20: and 20-40 Kev. were appropriately subtracted from the counted numbers. The corrected experimental curve was plotted along with the expected values in 5 Kev. intervals calculated using the Fermi and K. U. theories. (graph 4).

Conclusions

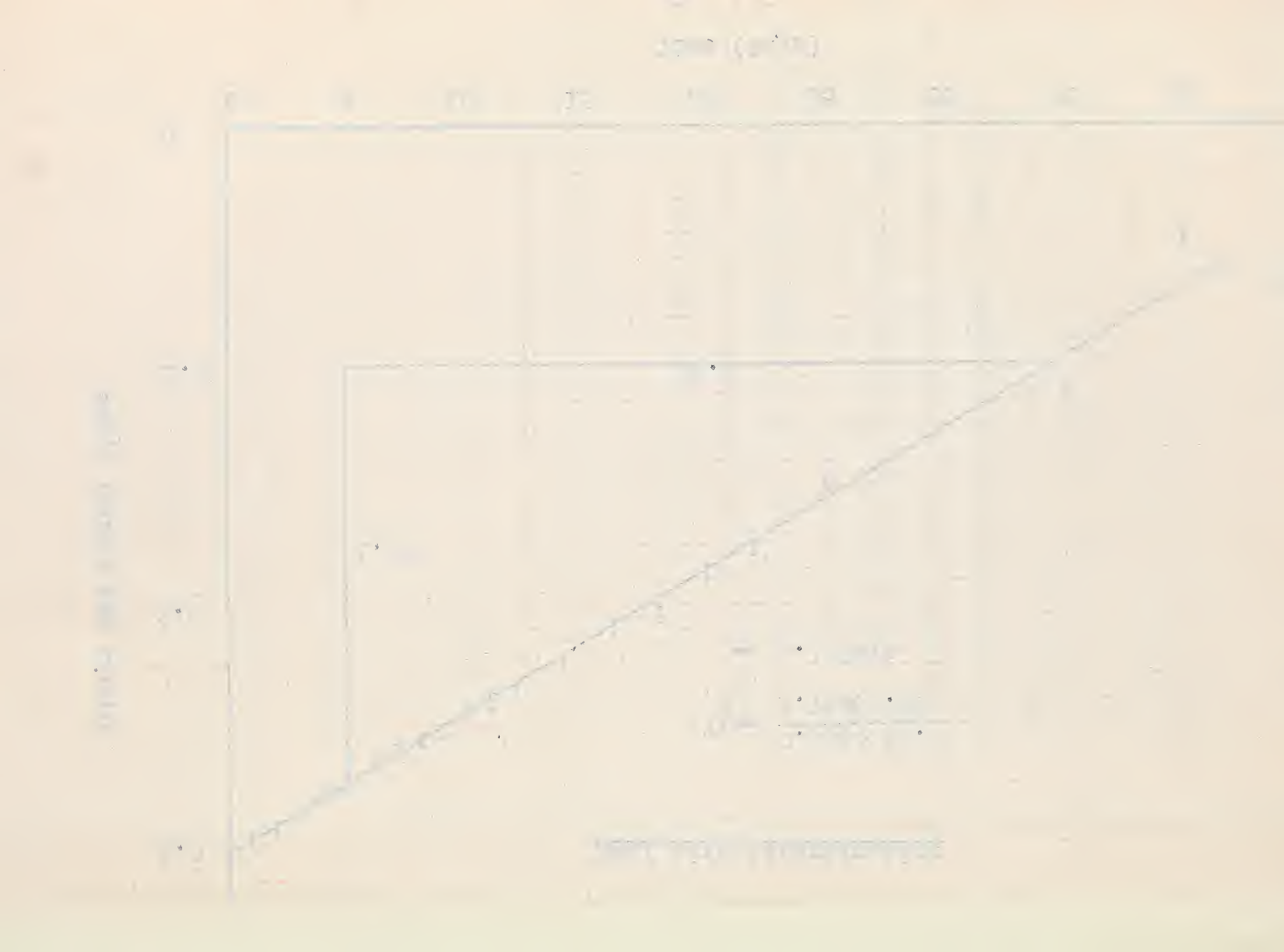
From the experimental data there appears to be a group of low energy particles between 0-65 Kev. emitted by RaE of about 0.06 per disintegration which exhibit a maximum between 15-20 Kev. The height of the peak is about 1/5 that of the theoretical maximum at 400 Kev. These results agree with those of H. O. W. Richardson (1), Waltner and Rogers (9),(10), and Madsen (11), in that a maximum was obtained at the low energies. The position of the peak obtained by the different workers varies between 15-30 Kev. Another peak at 55 Kev. obtained by H. O. W. Richardson was not found in this experiment.

This suggests either that the Fermi or K. U.

theories are not in agreement with these observations, or that RaE is isomeric. If the latter is true, one would expect a difference in the half lives of the two modes of disintegration, with the lower energy having the longer half life. The check on the half lives of the two modes, if there are two, would be interesting, but cannot be done until several half lives of the 5 day RaE have elapsed. This will be done, but cannot be included in this report.


Half life determination
$T_{\frac{1}{2}} = \frac{0.693 \times 29.5}{1.75 \times 2.30}$
= 5.1 days
3.0
2.0
1.0
0
1.75
29.5
Log_{10} counts per minute
0
5
10
15
20
25
30
35
40
Time (days)

Graph 5



Summary

By measuring the ranges of the low energy beta particles of RaE in a cloud chamber, an energy distribution curve from 0-65 Kev. was obtained. There appears to be a group of low energy particles of about 0.06 per disintegration with a most probable energy between 15-30 Kev.

The number of low energy particles due to the presence of RaD and branching were calculated and the correction applied to the experimental distribution. These corrections failed to account for the maximum obtained.

There is the possibility that RaE is isomeric, and a test for this will be carried out at a later date.

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Appendix 1

Preparation of vinylite films for source supports.

A solution of 250 mg. of vinylite with 10 c. c. of pure chloroform was prepared using vinylite discs obtained from Dr. Morrison of the Department of Chemistry. A 1000 ml. beaker was carefully cleaned with HNO_3 and filled to within $\frac{1}{2}$" of the top with distilled water. Then by using a fine tipped eye dropper the solution of vinylite and chloroform was placed on the top of the water one drop at a time. A thin layer spread out over the surface, and when the chloroform evaporated a thin vinylite film was obtained. The thickness and uniformity of the film was determined by the interference of the reflected light. The desired thickness of film could be obtained by adding either more chloroform or vinylite to the solution. When a film of desired thickness and uniformity was obtained it was lifted off on the support described under Apparatus. Three source supports were prepared at one time in case of later breakage. The film used in these experiments was 0.3 u thick.

Appendix 2

Film, Developer and Fixer

Linagraph-Ortho high speed 35mm. film by Kodak was used to record the tracks.

Developer D-19

For 1 British Gallon.

Water (50 degrees centigrade)	2400 c.c.
Elon	10.6 gms.
Kodak sodium sulphite (dessicated)	461 gms.
Kodak hydroquinone	42.3 gms.
Kodak sodium carbonate (monohydrated)	268 gms.
Potassium bromide	24 gms.
Cold water to make 1 gallon.	

Fixer Bath F-5

For 1 British Gallon

Water (50 degrees centigrade)	2880 c.c.
Sodium thiosulphate (Hypo)	1150 gms.
Sodium sulphite (dessicated)	72 gms.
Boric acid (crystals)	36.0 gms.
Potassium alum	72.0 gms.
Cold water to make 1 gallon.	